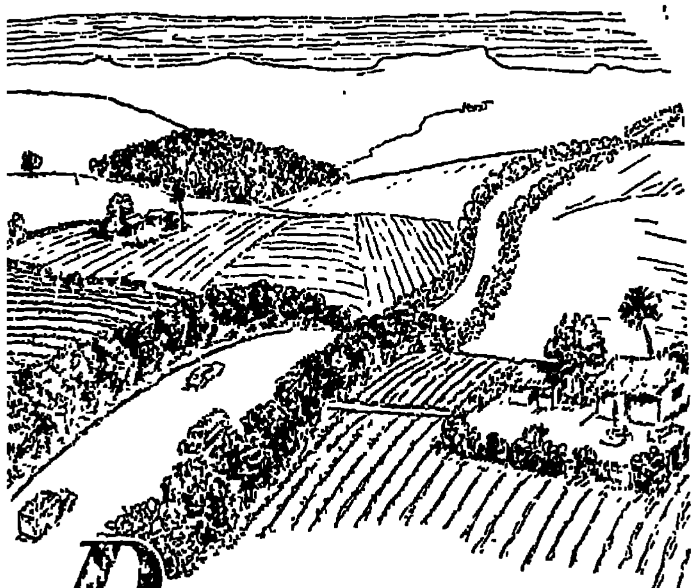

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Proceedings of the Eighth Meeting of the Indian Roads Congress

Volume VIII, Part 1. Gwalior October 1943.

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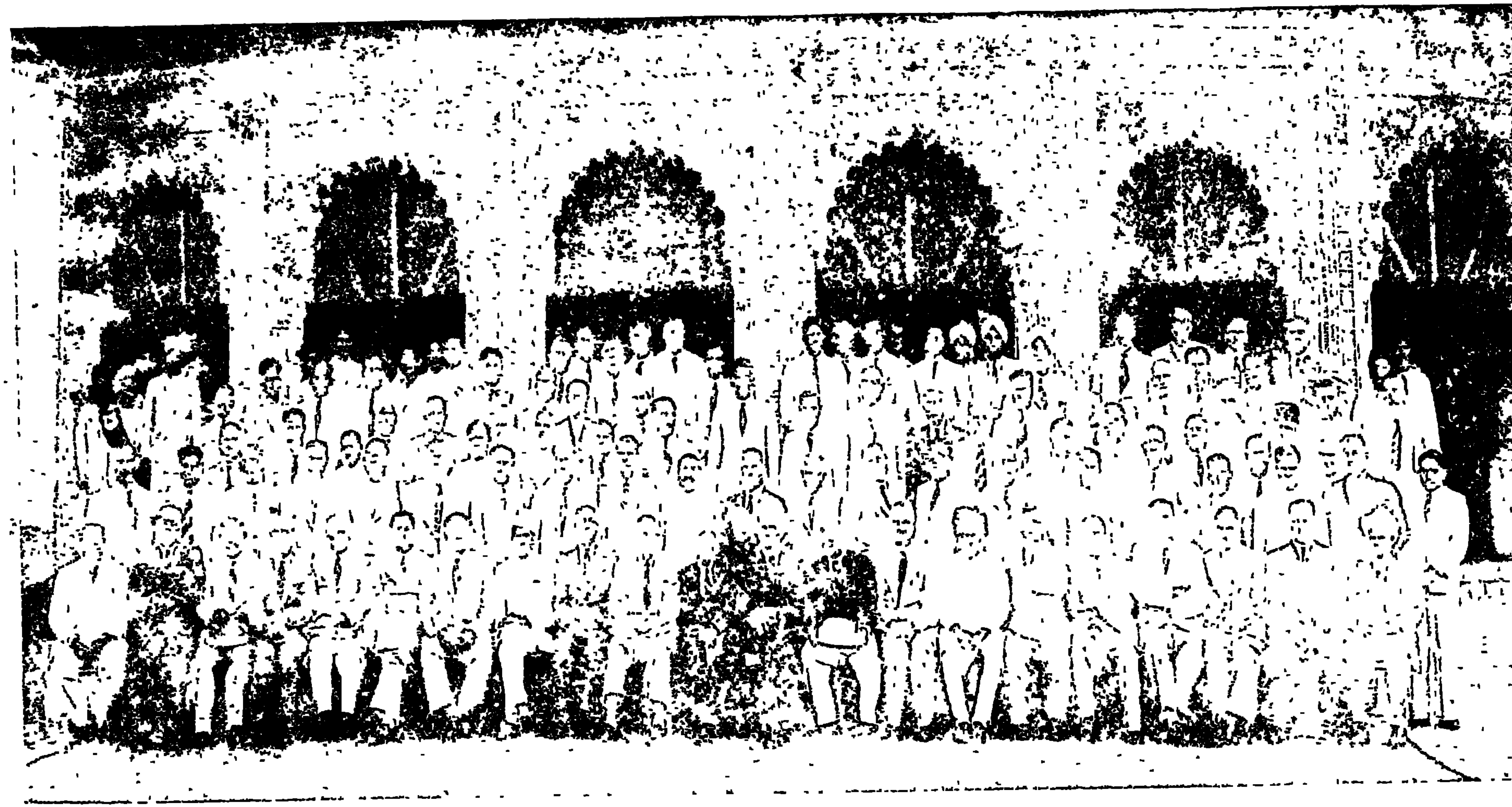

The Indian Roads Congress—Eighth Session, Gwalior, October 1943.

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President, 1943-44

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Established 1931. *Registered 1937.*

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PROCEEDINGS OF THE EIGHTH SESSION OF THE INDIAN ROADS CONGRESS HELD AT GWALIOR FROM THE 1ST TO THE 7TH OCTOBER, 1943

The Eighth Session of the Indian Roads Congress met at 11 a.m. on October 4th, 1943, at the Assembly Hall, Moti Mahal, Gwalior

The following members were present :—

Government of India.

1. Sir Kenneth Mitchell, C.I E.
2. Mr. J. Vesugar
3. Mr. K. S Raghavachary.

Central P. W. Department.

4. Mr A W. H Dean, C.I.E.
5. Mr G. M McKelvie.

Madras.

6. Mr T. Lokanatha Mudaliyar.
7. Mr. N. T. Gnanaprakasam.

Bombay.

8. Mr. W. H E Garrod.
9. Mr N. V. Modak.
10. Mr. E A. Nadirshah.
11. Mr. A. S. Adke.

Bengal.

12. Lt -Col John Chambers.
13. Mr T. Mitra.
14. Mr. R. K. Bose.

United Provinces.

15. Mr Mahabir Prasad.
16. Mr. J. C Sahney.
17. Mr. James Harris.
18. Rai Sahib Fateh Chand.

Punjab.

19. Mr. S. Bashiram.
20. Mr. S. R. Mehra
21. Mr. G. C. Khanna.
22. Mr. Abdul Aziz.
23. Mr. R. N Dogra.
24. Mr L. A. Freak.

Central Provinces.

25. Mr B. St. J. Newton.
26. Mr. S. N Tripathi.

Bihar.

27. Mr. W. L. Murrell.
28. Rai Bahadur M. L Bahl.
29. Rai Bahadur Chandi Prasad Misra.
30. Rai Sahib S. K. Ghose.
31. Rai Bahadur Gauri Shankar Ram.
32. Rai Bahadur M. A. Rangaswamy.

Assam.

33. Mr. Ali Ahmed.
34. Mr. Devi Dayal.
35. Chaudhari Imam-Uz-Zaman

Orissa.

36. Mr. P. C. Das
37. Mr. B. N. Sahu.

Sind.

38. Mr. J. M Rijwani.
39. Mr. S. S Divatia.
40. Mr. G. B. Vaswani.

Central India States Agency.

41. Mr. N. A Khot.
42. Mr. Mohison Ali.
43. Mr. Chandra Prasad Saksena.
44. Mr. B. M. Rao.

Rajputana States Agency.

45. Mr. T. C. Pandya.
46. Rai Sahib S. R. Sahgal.
47. Mr. F.F. Ferguson.

Western India States Agency.

48. Mr. Upendra J. Bhatt.

Baroda States & Gujarat States Agency.

49. Mr. M. K. Jadhav.
50. Mr. G. K. Patil.
51. Mr. M. P. Rathod.

Madras States Agency.

52. Mr. I. C. Chakko.

Punjab States Agency.

53. Khan Bahadur J. R. Colabawala.
54. Mr. S. D. Dhodi.
55. Mr. L Sri Ram Puri.
56. Mr. R K. Samdani.
57. Mr. Jogindra Singh.

Hyderabad State.

58. Mr. Md. Farhatullah.
59. Mr. Dildar Husain.

Gwalior, Rampur & Benares States.

60. Captain N. K. Bhonsle.
61. Mr. Zakaullah Khan.
62. Mr. R. J. Dhumal.
63. Mr. Y. G. Mane.
64. Mr. B M. Johri.
65. Mr. Hari Shanker.
66. Mr. K. L. Handa.
67. Mr. N M. Malik.
68. Mr. S. R. Inamdar.
69. Mr. P. V. Divatia.
70. Mr. A. G. Vaidya.
71. Mr. M. K. Dixit.
72. Mr. P. M. Choudhri.
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74. Mr. H. J. Jadav.
75. Mr. B. N. Sharma.
76. Mr. D. V Moghe.
77. Mr. B. G. Naik.

78 Mr Rishi Raj.
79 Mr. D K Mathure
80 Mr K. R Ghatge
81 Mr S. T Prokofieff
82 Mr Narayan Rao Naidu.
83 Mr Paul Y Krishnarao
84 Mr S N Datta
85 Mr. Susil Chandra Gupta
86 Mr V L Athavale
87 Mr K. M Gupta

Kashmir State

88 Mr. S B Tyabji

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93 Mr B V Vagh.
94 Mr. T. R S Kynnersley.
95 Mr Ian A T Shannon
96. Mr V N Rangaswami.
97 Mr C J Fielder.
98 Mr D B Nagarkar.
99 Mr Nur Mohammad Chinoy.
100 Mr. T Campbell Gray

PRESIDENTIAL ADDRESS
By SIR KENNETH MITCHELL.

Among the distinguished guests who attended the formal opening of the Congress were, Sir Gurunath Bewoor, C.I.E., I.C.S, Secretary to the Government of India, in the Posts and Air Department, C. G. Herbert, Esquire, C I E, I C.S., the Hon'ble Resident at Gwalior, Ministers and Members of the Government of His Highness the Maharaja Scindia of Gwalior and other *elite* of the town

The Session was formally opened by RAJAMANTRAPRAVINA S P. RAJAGOPALACHARI, B A, B L, Home Member and Vice-President of the Executive Council of His Highness the Maharaja Scindia of Gwalior in charge of the Public Works Department.

In asking RAJAMANTRAPRAVINA RAJAGOPALACHARI to open the Session, SIR KENNETH MITCHELL, C I.E, Controller of Road Transport, War Transport Department, Government of India, and President of the Indian Roads Congress, delivered the following address .—

Before we commence the proceedings, I would like to read with your permission, Sir, a letter which I have received from the Hon'ble Sir Mohd. Usman, Member of the Viceroy's Executive Council for Posts and Air. ·

"I regret I have been unable to accept the kind invitation of the Government of His Highness to be present at the session of the Indian Roads Congress at Gwalior I am aware of the excellent work done by the members of the Congress in connection with the development of roads in India The Government of India are fully aware of the great importance, from the national point of view, of an extensive and well co-ordinated road system for India, and they have at present in hand the preparation of plans for post-war development. I am sure that the labours of the Congress would be extremely helpful in the task which Government have undertaken. I request you to convey my greetings to the members of the Congress now assembled in session and I wish all success to their labours."

It is not quite nine years since this Congress started life at Delhi in December, 1934. Since then, we have had five more increasingly useful annual meetings. Since December 1939, however, we have had only one Council meeting and no full session. Many of us have been too busy with

war work to find time for the necessary preparations, or to attend meetings. Most centres are now overcrowded, and accommodation not to be had. Nor did we think we should add even our small quota to the overcrowding of trains. Many of us have been disappointed at this lull and have feared that it would set us back, and members lose interest. I believe, however, that the spirit of unity and progress among Road Engineers from which this Congress was born, will have been an adequate cement to hold it together through this period of inactivity, and I am quite certain that the attendance here today more than justifies that belief.

2. But war clouds are now lifting, there is a promise of a fair future, and it is right that we should meet, to consider the vital business of planning for post-war developments and to prepare ourselves jointly and severally for the great work ahead. We are, therefore, most grateful to His Highness the Maharaja Scindia and His Highness' Government for having made this meeting possible and for the truly excellent arrangements made for us. We are also most grateful to you, Sir for coming here to-day to open our formal proceedings.

3. Of our six previous meetings, four were held in British India and two in States. This meeting makes the score more even and demonstrates the common interest of the whole of India in good roads. It is, moreover, appropriate to meet here at Gwalior, which lies on the second great highway of Northern India—the Bombay-Delhi Road. Some 350 miles of this road, I think, are in His Highness' territory, including many miles of excellent red laterite surface, as well as about 50 miles on either side of Gwalior which has the most intense bullock cart traffic on ordinary stone metal. This presents a problem soluble only, I believe, by traffic segregation.

4. We must still save road transport and petrol. It has been rather unfortunate, therefore, we have not been able to travel so far and see so much as we should have liked of the roads and of recent developments here. But if the State has not a large milage of modern surfaces, it has, if I may presume to say so, for many years been progressive in the building and maintaining of metalled roads and bridges, both for through communication and for rural development. The Bombay-Agra-Delhi Road, for instance, was previously subject to serious monsoon interruptions, in Bombay and Central India as well as in Gwalior. It has, with the help of the Central Road Fund, been bridged at most of the worst places, among them the Tapti in Bombay and the Parbati in Gwalior. There remains, of course, the formidable Chambal, at Gwalior North boundary. Much also of the Indore-Ajmer road lies in Gwalior, although the missing links, which have now been supplied, lay mainly in other jurisdictions. Another Road Fund work which affects Gwalior, although outside it, is the improvement, not yet complete, of the Kotah-Baran-Thana Road which connects Kotah and the Rajputana road system generally with the Bombay-Delhi Road near Shivpuri. From Shivpuri to the East, you have the trunk road to Jhansi and Cawnpore, which joins with the Grand Trunk Road, Delhi-Calcutta. Gwalior thus includes important sections of the main North to South and East to West road routes of North-Central India; and is a key point on the long distance trunk or National Highway system of the country. We wish we could have seen more of these roads and of the extensive network of rural roads of which the State

is justly proud. Perhaps on some future occasion, the Congress will be invited to meet here again and be able to see more

5. But to turn now to all-India questions. Obviously, practical planning for the future is now in the air. We have a clear assurance of this in the encouraging message I have just read you from the Hon'ble Sir Mohd Usman. In the last few weeks also, we have had an important speech from His Excellency Sir Maurice Hallett, stressing the need for planned road development and the use of all forms of land transport; we had another speech from the Honourable Mr. Parker at the annual meeting of the Indian Roads and Transport Development Association, making some trenchant criticisms of the failure of the Road Fund to produce the results expected of it, and giving us some thought-provoking ideas for the future Whatever may be the disappointment at the Road Fund results, I am sure that Mr Parker would agree that, by and large, the Engineers have faithfully and skilfully applied the money that was given to them, and that where money has been given, substantial improvement has resulted. Be that as it may, our immediate concern, as representing the Road Engineers of this sub-continent, is now to look forward to big things still to be done rather than to pride ourselves on the modest achievements of the past or to steel ourselves to renew the old road-rail disputes We cannot be satisfied with things as they are, and we should look back not with complacence or satisfaction or anger at frustration, but solely in order to harness our experience to our future problems.

6 When we founded this Congress, we intended, as our guiding rule, to keep our activities within the purely professional engineering field, and to avoid intrusion into administrative and financial questions That is a salutary general rule which we have kept and will continue to observe, particularly in matters of administrative detail But we claim and I think with justification, to know more about roads, their possibilities, and what is wrong with them, than any other body of men; and there are times such as the present when we are entitled to say, and should say, what we think on the larger non-technical aspects. The views on these aspects which I shall now put before you are primarily my own, but, I believe, generally reflect the opinion of this Congress, although, where thought and interest are so keen, there must be differences on fine detail.

7. Looking back then, the better to look forward, the greatest defect has, I suggest, been failure to apply the best available skill, experience, and energy to the improvement of the roads upon which so largely depend the social and material welfare of the rural population, that is, the humble country roads. To generalise, it is fair to say that village roads and the humbler district roads have not only not progressed but have deteriorated with the increasing traffic due to more money crops being moved, more people, and more travel arising from security and general awakening There has thus accumulated a burden of arrears of overdue improvement which is sometimes staggering to contemplate I for one believe the remedies to be possible, but in any case the facts must be faced. There are hundreds, probably thousands, of large villages, at some distance from any roads supposedly maintained by public authority, and many miles from any modern road, and there is, I fear, general neglect of the link between the village and the public road, which link is what we mean by a village road. The people

in those villages are the primary producers of crops and revenue. Every maund of exportable foodstuff, cotton and other raw materials of agriculture, originates in the village and starts its journey to market along the village or unmetalled district road, and the service which the country and the people now get from these roads is quite inadequate.

8. In Bengal and parts of Bihar, I believe that village roads are in the charge of Union Boards. This may be the case elsewhere, but the more common case is that maintenance by public authority extends only to district board roads, and that the first and last link from the village to the district road is not properly provided for. These roads must, as a rule, of course, remain unmetalled, but a general campaign of widening, straightening, legal reservation of the land and the provision of culverts is necessary. That done, they must be kept up.

9. One kind of critic will ask what new miracle we suppose can be worked on *kachha* village or district roads, with which nothing, they say, can be done for the very good reason that nothing ever has been done. The same appeal to established custom is made too, when we suggest improving the bullock cart. Our answer is that we are practical optimists and do not believe that things can or should be left, as they are In this competitive world, easy means of communication and mechanically efficient means of transport to markets are in their right degree as essential to the primary producer in the village as they are to the great manufacturer in the town. All other schemes for the Social, Political and material advancement of the people and for the prevention of disease will fail if the village remains isolated by bad roads. Let us for a moment take a peep into the future of India, say 50 years ahead. What is it that we hope for ? Is it not a country of better fed, better clothed, better educated happier people, working in thriving industries with extensive overseas markets and in scientific farming probably with larger holdings and greater production. Has this picture any place in it for the present primitive village and district road, deep in dust or mud with its toiling overstrained cattle and creaking inefficient cart ? I say definitely no, it is not, and if you cannot conceive of these roads being still as they are 50 years hence, then why not start on them now ? Indeed, their condition is a serious obstacle to the achievement of the rest of the picture

10. Physically, that is apart from administrative and financial aspects, the condition of earth roads, village or district, is due to four things: first, the nature of the soil; second, the climate and rainfall; third, the way in which the road is made up and maintained ; and last, but by no means least, the nature and intensity of the traffic. The climate we cannot change, the soil we cannot alter greatly, although improvement and stabilisation are possible with intelligent and timely maintenance. But all of these may be partially defeated, by the nature of the traffic. This Congress preaches the logic that if you cannot improve the road for the traffic, you must try to improve the traffic, that is, evolve a bullock cart that will be less damaging to roads, and also a more efficient transport machine. This has caused some controversy. We are told that our job is to make roads fit to carry any traffic that may use them, and that it is not our job to dictate to the traffic. The truth is that, given money, we can make roads for any sort of traffic from a bicyle to a tank, but since the money needed for a really good road system for

the present bullock cart will be immense, we suggest that the cart, after a reign of 5,000 years, is due for some improvement. We are also told that to modernise the cart will destroy the living of the village craftsman who makes and mends it. Why should it be assumed that the village craftsman alone will stagnate and be unable to service a more modern and better built cart ?

11. Among the post-war plans for expanding Industry, I suggest that there are two things which in India require improvement, the bullock cart and the various forms of locally made inefficient water-lift. These merit the attention of the progressive industrialist, affording at once a new industry and better machines for the agriculturist This might for a time damage the hand labourer in the village, but it would surely be to the long-term interests of rural economy that it should be served by more efficient machines. As regards the cart-wheels it is an indisputable and unalterable fact that if the carts using the roads had pneumatic tyres, not only could the community be given many more roads for the same money, but the better roads and carts would enable greater loads to be carried with less exhaustion of bullock power. The use of rubber tyres on carts would, for instance, open up immense possibilities for the simple brick paved road. Despite the work of Mr Murrell and others, to whom we are all indebted for their efforts, no other visible alternative to the present tyres and wheels, promising as it may be, has anything like the better road possibilities of the pneumatic tyre. The pneumatic tyres are made in India and, as I have suggested, the cart could be also. In saying this I do not wish for a moment to disparage the very great work, the very great enthusiasm which Mr. Murrell has put in the evolution of these cart wheels Naturally, as he says, there is opposition to these pneumatic tyred carts; and we should have a second string to one bow But at the same time I do not say that we should assume that in a progressive country pneumatic tyred carts are impossible to get

12 Much of the argument about rubber tyred carts presupposes that we want to convert them all, which financially and practically, they say, is absurd I hope that it will not be necessary to go to that length My theory is that there are far more carts being used for purely agricultural work in the fields than are necessary to market crops and do other road carting. With many diversities of marketing trade practice, it is difficult to generalise, but it is probably true that in the majority of cases the producer can carry his crop to market in his own cart at no cash cost to himself. To restrict this work to a limited number of rubber tyred bullock carts would, therefore, mean that he would often have to pay someone else to do his carting for him. This might be true, but the price will be a small one to pay for the incalculable benefit of better roads all round What we want to know, and what we have been pressing for, is an enquiry into the facts, *i. e*, how many rubber tyred carts be needed, how many carts can be used and what is the maximum number that can be counted. This is a competitive world and an age of specialisation, which simply means that India cannot progress by the use of the old tools, the old carts, and old customs, as these are sacrosanct.

13. To return to the village road. The need for permanent improvements, and capital outlay on making a permanent alignment with adequate width, proper grading, drainage and culverts, is clear. Soil stabilisation is not quite so simple, but it has great possibilities and we are always learning more about it. But, in the long run, the essence of the

matter is proper maintenance, and that, in the case of village roads, is, I suggest, a matter of free labour by the villagers themselves, managed by their *panchayats* or like bodies. This idea is objected to by some as a reversion to something akin to *Begar*. There are, however, several severely practical reasons for it.

14 In the first place, any low-cost road depends on the clay content of the soil as the binder, and, as we know, proper maintenance requires not a regular labour force or haphazard earthwork, but prompt treatment at the right time when the soil is neither too dry nor too wet. Three or four men, with a pair of bullocks and a simple wooden drag, can then in a few hours restore camber, fill the ruts, and consolidate the whole, so as to keep the road in shape for several weeks. At other times, little or nothing can be done. This work surely is for the man on the spot, who knows when and how, or would soon learn, and not for a distant departmental subordinate, who cannot be expected to tear round the country hiring men and cattle for a day or two at the critical time for the different sections of the road just when the psychological moment arrives. The work requires a working knowledge of the behaviour of different soils which the men who are always working in them can best supply. Whether, therefore, there be cash payment or not, I am sure that village road maintenance could be better done at less cost by the villagers than by anyone else. Moreover, given help in the lay out, grading, and location of culverts, I suggest that the work of initial improvement also be undertaken by the villagers and as far as possible by free labour The demands for increased expenditure, both first cost and recurring, for all schemes of post-war development will be so immense that self-help will be necessary, wherever it is possible, and if a drive to get the villagers to improve their own roads themselves accompanied a real programme to improve the district roads at public expense, I believe that it would succeed. The Engineers would help, but the drive for the improvement of the purely village road, encouragement, and general supervision would need the very active co-operation of the departments dealing with rural uplift, village sanitation, consolidation of holdings, and so forth.

15. I have taken much of your time in discussing village roads, because of their great importance in any balanced scheme of development. I believe as firmly as anyone in the necessity for really first class trunk and main roads, but in retrospect it seems to me that the usual classification of trunk, main, district and village roads has come to be too readily accepted as an order of importance. Each class is equally important in its own way, and it is a good thing sometimes to consider them in the reverse order, starting from the origin and terminus of all rural transport, the village.

16. Before turning to the next class, that is district roads, I would like to tell you a little story. The United States of America have, as you know, an immense milage of magnificent concrete and other high-cost roads, but they have also many miles of low-cost rural roads, the maintenance of which they have brought to a fine art. Not long ago, somewhere in Eastern India, driving over a low-cost road, in really terrible condition, we picked up two American soldiers, who wanted a lift. After going along for sometime, I said something about the road being bad, and one of them remarked that it would be all right if someone would give it a little maintenance. Now, that was the American

reaction The reaction of the ordinary "man in the street" in India would have been that the road must be made *pakka*, that is to say, it must be metalled. In America, they know what can be done by proper maintenance of low-cost roads ; people in India do not know it, because it has too long been neglected as hopeless, and it is this mentality, coupled with the strongly entrenched position of the earthwork contractor, that accounts for a good deal of the neglect of district roads

17. So, we come next to the district road, by which I mean the great milage of roads lying in the class between the trunk and inter-town routes on the one hand and the village road on the other. This is the class of road on which the rural population very largely depends It is normally in the charge of rural local bodies, but it has been very badly neglected. In planning for the future, we have to study two things, the adequacy of the system in accessibility and in condition. Accessibility, if measured by the formula which I have already suggested that no village of say 1,000 population and over, should be more than, say, a mile or half a mile from a public road ; the precise formula will depend on the size and distribution of villages Condition of the road depends on the equation of the specification to the traffic.

18. Now, the present general condition of this extensive system of district roads, some metalled, many more unmetalled, seems to me to be a reproach to our generation and also a barrier to every other plan of rural uplift or improvement. We in this Congress have studied roads of all classes for most of our professional lives and know that there is no simple universal cure. The problems are of great variety, calling for different treatments. But what is, I fear, a common cause of the present state of affairs, common to nearly all Provinces and districts, is an administrative misfit. Having spent many years in the study of these problems in the Province in which I served, and in close contact with district boards, I claim to be an impartial and I try to be an honest observer. As I see them, two simple facts are inescapable. On the one hand, local self-government has had a long and fair trial ; on the other, the roads are no better. This administrative machine evidently does not fit this particular kind of work. One reason often advanced is financial, that district boards have not the money, nor the taxing capacity, to discharge properly all the expanding functions that have devolved upon them, in education, public health and all the rest, as well as roads This is probably true, although I fear that even the money budgeted for roads could often have been better or more wisely spent. Still, it must be accepted that the financing of post-war development and the overtaking of years of neglect will be quite beyond the existing and potential resources of local bodies, and probably also the maintenance of the resulting improved system This is not, I suggest, a matter for doles or pauperisation of these bodies If the business is financially beyond them, they should, I suggest, be relieved of it. It seems to me to be a sound axiom of public finance that the Government, Legislature, or local body that imposes the taxation should be directly responsible for the use of the money and answerable for its abuse or waste. The system of doles from Provincial revenues to local bodies and from local bodies to similar smaller bodies ignores this Moreover, it cannot be too often repeated that the problem with this class of road is maintenance more than the occasional finding of large sums for development The large sums for post-war development will come, when they come, from sources other than local rates, and if maintenance is later neglected, those large sums, or a good proportion of them, had better not have

been spent at all. It would be most unwise, therefore, for Provincial Governments to spend largely from capital on the development, and to leave the maintenance of the roads to others. It is no part of my business to pass in review the details of the administration of local bodies or to criticise this or that aspect. As a practical man, I merely say that there is nothing in the past history of roads to justify the hope that the same administrative machinery and the same local rates, acutely sensitive to the vagaries of the monsoon, will solve the road problems of the future.

19. There is one matter, however, on which, as an Engineer, I must venture to comment somewhat critically. It is that the status and conditions of service of district board engineers are often not such as to make for efficiency. Deprived as they frequently are, of any support and guidance from official professional superiors, they are always in danger of stagnating and dare not experiment, or try to get out of the grooves bounded by conservatism and the vested interests of contractors. I must, of course, except Madras where a more advanced system is in force. One reason for the generally poor conditions of service of district board engineers seems to me to lie in the accountant's device of relating establishment charges to cost of works and repairs. There is much truth in this rule of thumb when applied to self-contained construction works of magnitude. In its application to road maintenance, it is dangerous, since it elevates, as it were, the man who spends most and degrades the man who saves most by close application of scientific low-cost methods.

20 Again, the science and art of road-making and maintenance are advancing all the time. We can learn much from each other and from other countries, and we cannot afford to do without this learning. This Congress has been set up to promote it. Even so, with his many pre-occupations, the average district board engineer has not time to keep himself up to date, and to isolate him and his problems in each district must mean obstruction of progress. There is also the practical aspect of the use of machinery. As time goes on, more and more of our district road work may be done by machines. The maintenance of those machines and the provision of the mechanical engineering staff by independent district boards is uneconomical. This can already be seen in the matter of steam road rollers. It is a truism that the size of the world is virtually shrinking, and it is also a fact that you can to-day get over half a province in no more time than it took 20 years ago to get over a district. The Province has in fact become a suitable area for road management, and the isolation of district management is no longer necessary, nor is it desirable.

21. Therefore, I believe that the first step towards the improvement of district roads is to transfer them to expert Provincial Highway Departments, which would absorb the efficient district board engineers and level up standards of efficiency all round. It is a proposal that would be distasteful to the conservative among district board members, who would doubtless, and entirely paradoxically, call it reactionary. But if we are not satisfied with the service given by district roads in the past—and who can be?—we must get away from the things of the past. Reforms must be radical and must get much farther than merely pouring more money into the old machine. The irrigation works of India are unparalleled in any country. It is not always remembered —indeed, it is probably not realised—that the rates and fares on Indian railways are lower than in any country in the world bar one, and that means,

among other things, efficient engineering construction and maintenance. In their way, on the basis of cost, our Provincial and State main roads will bear comparison with those of many other countries who have not our difficulties of climate and mixed traffic. Now, these things have been done by organised services of engineers in departments of Government, and such an organisation I suggest, is now necessary for the development of roads. The future road problems are immense. Therefore, I say, let our engineers be organised into regular Highway Departments, and get to grips with those problems. The knowledge and skill and I would add, intense enthusiasm, are there to use.

22. These are large administrative questions, and in referring to them I have permitted myself some licence, since I am no longer connected officially with road administration These questions need not, however, delay the preparation of plans for future district road development which must be pressed forward in two stages. First, whether and where an extension of milage is necessary. This can be planned district-wise. The second and more complex question is the engineering estimation, based on actual traffic-counts or estimates, of what has to be done to improve the system to present-day needs Here, the first step seems to me to be to determine what in all local circumstances is the limit, in terms of the usual traffic interpretation, to what can be carried by improved earth roads; what milage remains and what improved surfaces, or devices like track-ways are possible with the materials most readily available. These improved specifications, as well as earth road improvements, can then be approximately priced per mile and the whole picture reviewed without the preparation of detailed estimates. The latter should then be put in hand for the most urgently needed improvements first, that is, for the improvement of the surfaces most over-loaded by present traffic

23 It is, in all, an immense task that should be taken up at once; but if systematised, it is not unmanageable. And, here, I would like to refer to the pilot schemes undertaken in the Bombay Presidency by the Indian Roads and Transport Development Association. This method of "sampling" the problem is most illuminating, and we are all grateful to the Association for their initiative in this matter and to Mr. Kynnersley for his interesting explanation of the two sample or pilot schemes.

24 This brings me to the two last classes of road, the two great All-India Highways and the main provincial Inter-town roads These two classes have already been developed to standards relatively far in advance of the others and are the two with which the general run of members of this Congress have in the past been most closely connected. These roads are still far below the standards necessary in modern times, and the war has revealed many weaknesses or missing links, particularly in the All-India Highways I believe that the future will tax the capacity of all available means of transport, and I do not propose to defend on any economic basis the necessity for a national highway system There are many reasons why this must be developed, but we can content ourselves with the simple one that we cannot do without it. Both these two classes of roads, that is to say, the National Highways and the trunk roads involve very much the same engineering, administrative and money problem and I propose to discuss them together.

25. In the future development of these roads this and the rising generation of Engineers will be called upon to apply the highest developments of the

science and art of economical road-making and maintaining. You will, I hope and believe, be able, in large scale planning, to approach costs from the long-term scientific angle rather than from that of what is cheapest in first-cost: your responsibilities in this and other matters will be very great. As one about to depart and leave you to it, there are many "don'ts", I would like to put before you, but I have already taken up a great deal of your time and will only offer you some random thoughts on different aspects. If some appear to you to be of minor importance, my excuse is that they have in the past been neglected or imperfectly understood.

26. My first general suggestion is the future importance of traffic segregation and the need for a full examination of the possibilities of this before any large schemes of development go too far. Motor transport will increase and will first displace, I believe, the horse vehicle for passenger work. But the bullock cart (I hope an improved cart) will probably remain the prime mover of agricultural produce as the short-haul transport for many years. We must at least plan on that basis. The bicycle is multiplying and will multiply rapidly; and we have to provide also for herds of cattle, flocks of sheep and goats, in some Provinces strings of camels, and everywhere the pedestrian. Now, elaborate segregation will not obviously be possible everywhere. But where traffic is dense—particularly where it is necessary, that is on the approaches to towns—to put all this mixture on to one common carriage-way by mere widening and more widening of the original metalled road, is to perpetuate inconvenience, congestion, and risk of accidents. It will also, I believe, be far more expensive to make and maintain a great width of all-purpose surface than to provide each class with what is best suited to it. For instance there might be a black top surface for motor vehicles; a concrete road or concrete track-ways for the carts; a six or eight-foot cycle-strip of light concrete or black top; and a shaded way with a decent surface of some sort for pedestrians ; all this will only be giving what is actually wanted. If these traffic lanes, or some of them, can be separated by a fence or line of trees, so much the better. Even outside all this, and preferably on both sides, there should be a shaded way for cattle, sheep and goats. In planning, we must look forward and not merely remedy the present defects, by say, widening the existing carriage-way to double or treble its present width. Obviously, the trunk or main road of the future will require much more land width than is always available. Land is valuable and the Engineers have often been forced to be content with the barest minimum on to which to get a single lane metalled road, berms, trees, and drains. Many roads are now in consequence hopelessly cramped for the necessary expansion, and where the road boundary has been built up too, it is going to be a most difficult and expensive business to provide an adequate road. To those of you who will now plan the new developments, I would say, do not spoil the present and the future job by allowing yourselves to be cramped for land, if you can help it. There is also a very great need for enactment or amendment of highway legislation generally; and in particular for more effective remedies than now exist against encroachment on to road lands. Much money is going to be spent in the future in recovering land that once belonged to the road but which has been short-sightedly sold, or on which people have successfully squatted. A terrible example is to be seen on the Grand Trunk Road approach to Calcutta.

27. This brings me to the allied question of taxation of "betterment value" of land due to road improvement. The principle is accepted in

many countries, but its application to agricultural land values in India is limited by the smallness of holdings, and it is already supposed to be taken into account at the time of periodical settlements. The case of large estates on permanent settlement is different, as is also the sale of agricultural land for industrial development arising out of the improvement of roads, or for which road expenditure has to be increased. In the latter case, in particular, the sudden appreciation in value should be tapped. This also brings up the question of ribbon development which must likewise be controlled, i. e., the two things go together, the acquisition of land for road development and ribbon development.

28. Besides traffic segregation, there are other factors of road safety which need more attention, such as the by-passing of towns and villages, curves and super-elevation, blindness at changes of grade, and so forth Standard practice exists in these matters and should be followed more closely. More careful treatment of road junctions, and approaches to level crossings is also necessary I doubt whether the time has come for any general substitution of over-bridges for railway level crossings, although a number are needed where mutual interruption is excessive I suggest also that the "S" bends, so often introduced into the road to get a square crossing, are, on the whole, an advantage in slowing down the approaching traffic, but they are often too sharp and blind and need improvement It would, I believe, be an improvement if provision for many of these things were made in standard road building estimates. They are too often left to be met from contingencies and expected savings which do not result and there are certain aspects of modern road planning which have not heretofore appeared in road development and should be included in future Another source of danger is the unnecessary use of the motor vehicle caution signs and unnecessary severe speed restrictions. These merely bring these signs into contempt, so that the one that really means business is ignored and fatal accidents take place.

29 There is one other question and that is road æsthetics Almost any work of engineering well and truly built is in itself a thing of beauty, but that is not enough ; the will to beautify roads must be there, and you should call in the architect in all cases of town approaches and, I would add, bridge parapets and designs generally Above all, remember that your road, great or humble, is used everyday and will continue to be used when you have passed on. Therefore, build public service into it in every way and educate the young Engineers to this ideal

30 The education of Engineers, like that of other professions, begins at college and ends only on retirement from active life. Your Council recently invited members of this Congress to a prize essay competition on the education of the Road Engineer The essay adjudged to be the best was that of Mr. V. N. Rangaswami of Madras. One of the duties, I think, of your new Council must be, to draw up a memorandum on the subject for the various Engineering Colleges in the country and, if possible, to secure the production of a standard text book on Road Engineering in India.

31 Subsequent education depends on experience, on reading and on seeing what others do The Congress has built up a good lending library and circulates other information At these meetings, it provides opportunities for exchange of views and inspection of each other's work. It has, I believe,

done not a little to improve the individual efficiency and promote the continuing education of us all. It is, therefore, deserving of continued and increased Government support and encouragement. The Congress also keeps in touch with road progress in other countries, and its Council is the Organising Committee in India for the International Association of Roads Congresses. In the past, India has been sparsely represented at those Congresses by delegates who went, I fear, mainly to look, listen and marvel in comparative silence. In the future, when these meetings are resumed, you will have much to contribute to International knowledge. It may be some years before full International Meetings can be renewed, but in the meantime, zonal meetings should be possible; and India might well be the centre for an Eastern Group Roads Congress, at a no very distant date. I believe also that it would make for progress to arrange temporary exchanges of officers between Provinces; and it would certainly be good to have more travelling scholarships or some other means of providing that our younger Engineers have opportunities of first-hand study of the practice in other countries.

32. There, gentlemen, is a long but rather unbalanced sketch of what I hope will be a better balanced scheme of road development in the future, a scheme so arranged that whether it be a great National Highway or a humble village road, each will be equally well adapted to its purpose and traffic and equally well cared for. I would put it in this way. We want to improve the road-rupee-ratio all round and we want a certain plan that on every road the ton-mile-rupee ratio should, if not a constant, at least conform to some rational law. The methods and materials of construction and the cost of various classes will vary within wide limits, but there should be no variation in the service given in providing reasonably efficient, safe, and comfortable transport for passengers and goods. The immense benefits of such a system are obvious. As to the cost, I believe, with Mr. Thomas Macdonald, for very many years Chief of the U. S. Bureau of Public Roads, that "we pay for the roads, whether we have them or not, but we pay more for them if we don't have them." Obviously, with so much to be done, the cost of achieving an adequate road system will be very great, but it will be less if tackled systematically and scientifically on a broad plan, than if it is taken up haphazard.

33 It is not, I think, necessary for us to suggest hypothecation of one form of revenue or another to our purposes; the various receipts from taxation of motor vehicles and petrol are there for all to see. In any case, we must first see the whole picture and, ultimately, I believe that your future road plan will be accepted and the money found just to the extent that it appeals to the Governments and peoples of India as something which is not only good value for money but as something that they can no longer afford to do without. The preparation and presentation of the plans will depend largely, gentlemen, upon you. There is no time to be lost and you will very shortly be called upon to set to work. May you and the Indian Roads Congress prosper in that work.

34. Before I ask Rajamantrapravina S. P. Rajagopalachari to open the Session, I would apologise for the length of my address, and for any offence which I might have caused in my remarks about local bodies and roads. I assure them that no offence is intended to anyone, in particular or general; it is merely that in surveying the past for better view of the future, I have stated facts as I see them, and, I hope, impartially.

35 In now asking you, Sir, to open our proceedings, may I again express our gratitude to His Highness and his Government for making it possible for us to have this meeting and for the most excellent arrangements made When, in years to come, I read of the great strides made by India in road development, I shall like to think that the renewed enthusiasm and vigour of this Congress and its members dated from this Gwalior meeting.

Declaring the meeting open, Rajamantrapravina S. P Rajagopalachari said :—

GENTLEMEN,

1. It gives me great pleasure to welcome, on behalf of His Highness the Maharaja Scindia, this distinguished body of men from all parts of India, who compose the Indian Roads Congress, to this historic city of Gwalior. I thank you sincerely for the honour you have done me by inviting me to inaugurate this session of the Congress. I might mention that the Gwalior Government invited the Congress to hold its session here in 1939 It could not be held then, and we are glad that our request has now been complied with

2. His Highness the Maharaja Scindia, who takes a very keen personal interest in the road-problem, would indeed have been happy to welcome you personally, but unavoidable circumstances have stood in the way of his doing so He, however, trusts that you will enjoy your stay here and feels sure that the deliberations of your body will prove immensely useful to his government and to the whole of India.

3. I had the good fortune of attending the opening session of this Congress in Bangalore in 1936 and was very much impressed with its work and its promise for the future. I was, therefore, surprised to hear that the Congress had not met since 1939 and it has been only revived this year. I think the revival of this very useful body is most opportune at this time. The war-time difficulties which prevented your meeting till now are gradually lessening. The dark clouds which had gathered during the first years of the war are now clearing up, and we feel almost sure that it is only a question of time before final victory over the Axis forces is achieved. It is necessary, therefore, that we began to devote some attention to those post-war problems which have been exhaustively dealt with by Sir Kenneth Mitchell in his address It need hardly be said that the problems of peace, especially after a long and devastating war, are as numerous and as complicated as those during war-time. In this reconstruction which lies before us, the Engineer, and specially the Road-Engineer has a most vital part to play. It has been said that the good that a man does, dies with him, and is oft interred with his bones; but the good that a Road-Engineer does lives after him and is writ large over the face of the country A system of proper modern communications has been one of India's chief needs for a long time past. It is perhaps a sad legacy of the past that, at the beginning of the present era of mechanical transport, we were not very much road-minded in this country, and our organisation for the study and execution of road projects was small and unsatisfactory. By the planning and building up of such a good system, the Indian Roads Congress can make a most valuable contribution to the

economic prosperity of the country. I regard this session, therefore, as a momentous one, and the Gwalior State is indeed fortunate to be associated with this session which might well mark a turning-point in the brief history of the Indian Roads Congress.

4. This State has other and more abiding reasons for taking special interest in the proceedings of this Congress. As Sir Kenneth Mitchell has pointed out, the road system of Gwalior occupies a key position in regard to through road communications in this part of the country and in regard to rural roads. It stands high in the milage of roads per 1000 of population, and stands second bracketed with Bengal with ·55 miles of modern surface and water-bound macadam roads per 1000 of population, having been exceeded by Bombay alone with ·89 miles. A large part of the Bombay-Agra Road, which is one of the main trunk roads in India passes through the State. This portion has always been well-maintained, and I have it on the authority of our Chief Engineer that in the motor trials from Delhi to Bombay so early as 1904, the roads through Gwalior State were judged the best in the whole run. During the last few years about 21 bridges have been constructed at a cost of about 13 lakhs of rupees.

5. His Highness the Maharaja has been quite alive to the importance of the maintenance of these roads in as satisfactory a state as possible, and no effort is spared to meet the fastly growing demands on it. The compliment which Sir Kenneth Mitchell has paid to the State with regard to its roads is, I know, not a mere conventional one devised for the occasion; for he has often seen for himself the work done in the State and has given our officers every advice, encouragement, and help for which we are grateful.

6. The tasks which we had to face during the last few years on account of the enormous war-time traffic passing over our roads were indeed heavy. The roads could not be maintained according to the old methods in a fit state for all this traffic, and proposals have been made to have a modern surface on the Agra-Bombay Trunk Road, such as cement concrete or tar, etc. It is understood that the Government of India have very recently given a grant of about 8 lakhs of rupees for improving the Bombay-Delhi Road in the State.

7. It is, to my mind, high time that all the trunk roads in India as well as important lateral roads feeding them, are provided with modern surfaces, thereby avoiding the cumbersome method of annual maintenance, depending mainly upon that most uncertain factor, namely, the monsoon. These should be planned from now and executed over a period of years, according to their urgency and importance.

8. About ten years ago I paid a brief visit to the island of Ceylon, and I was surprised to find that nearly 70 to 75 per cent. of the road-milage was tarred, and one important trunk road from Colombo to Kandy had many modern conveniences, such as petrol bunks, telegraph and telephone stations, tea-stalls, etc., at very short intervals. They had the foresight to undertake the necessary initial expenditute, as, in the long run, it was economical and saved a lot of annual maintenance.

9. The conversion of the existing trunk roads in India into modern surface roads presents no engineering difficulty, but it is largely a question of policy and administration as well as of finance. Like Sir Kenneth

Mitchell, I look forward to the day when India will have a **National Highway** system with central and provincial organisations to maintain and develop it to the utmost extent possible.

10. The crux of the problem lies in getting necessary funds for the purpose. But if we capitalise all the annual expenditure that is incurred on our roads and convert them into modern surface roads, it would be of real permanent advantage to the country. In this connection I might bring to your notice a ray of hope which has been recently vouchsafed to us Field-Marshal Lord Wavell, the Viceroy-designate of India, in a speech on 16th September 1943 at the Pilgrims' Luncheon in London, said, "It has always seemed to me a curious fact that money is forthcoming in any quantity for war, but that no nation has ever yet produced money on the same scale to fight the evils of peace, namely, poverty, lack of education, unemployment, ill health, etc In the country to which I go, these evils have possibly to be met on a greater scale than anywhere else." I think we can safely add lack of proper communications to these evils. Such a statement, coming as it does from a soldier-statesman, who will control the destinies of India for the next few years, brings us some hope that beneficial schemes for the improvement of the country will not be put in cold storage merely for alleged lack of funds

11. I have till now touched only on the trunk roads and their improvement. But this aspect touches only the fringe of the road problem in India. In a great agricultural country like India, the most important question is, of course, communications between our rural tracts and the big commercial and marketing centres This linking of villages with the main arterial roads can be solved only by local efforts, as part of a general scheme of rural reconstruction. I quite agree with Sir Kenneth that self-help by the village community is the most feasible method of dealing with these roads, with a little financial help from the local government. Some such scheme has been successfully worked out in the Mysore State

12. I might also refer to another point which requires considerable planning, and that is the co-ordination of the various methods of transport which are likely to compete with each other, namely, road, rail, air, and water. You may perhaps remember that in the first few years after the war, when petrol was still easily available, there were some complaints that the users of roads were placed at a disadvantage compared with rail-transport. I do not know whether the complaint was well-founded, but it seems necessary that for the future these methods of transport should be properly co-ordinated with a view to achieving the best results from them. Perhaps the creation of a Central All-Transport Board co-ordinating the activities of the separate Boards, which we now have for road and rail traffic, etc., would go a great way to meet the situation.

13. I do not wish to take more of your time and to encroach upon your patience any longer I hope you will have a very successful session. Many of the members have come from long distances at great personal inconvenience. I trust that all the members attending this session will have a pleasant and restful time during their stay here so far as their work will permit, and will carry away happy memories of their stay here.

14. I now declare the Eighth Session of the Indian Roads Congress open.

COMMENTS

Col. Sopwith, who was not able to attend the Session due to ill health, has sent the following comments on the Presidential address :—

" I have read your Presidential address to the members of the Indian Roads Congress, given at Gwalior, with great interest. It was a matter of deep regret to me that severe fever compelled me to cancel at the last moment my attendance in Gwalior, the more so as I anticipate the Eighth Session to be the last that it would have been possible for me to be present at. Had I been there, I should have liked to take the opportunity to say something on the great subject matter of your address. As it is, although, like yourself, shortly leaving the scene of my activities, I take the greatest interest in the future of road development in India.

As the Author of the address, I venture to place before you a few observations which I hope may be of value. As you will see they are not adverse criticisms but I trust constructive ideas dotting the i's and crossing the t's of some parts of your address. I leave it to you to do anything you like with the contents of this letter including, if you do not think it worth while, nothing.

The particular points, on which I think that my comments may prove useful, are :—

1. I am glad to see, not only from your address but also from recent speeches by the Hon'ble Mr. Parker and others, that the importance of the village road as a factor in the economics of the country is at last being brought into prominence. I attach a copy of an article,* which I wrote for the Press some years ago, which stresses this point without going into detail, and my views are as strong now as, if not stronger than, they then were.

2. In paragraph 6 of your address you stress our guiding rule on foundation to have been " to keep our activities within the purely professional engineering field, and to avoid intrusion into administrative and financial questions".

I am doubtful whether this is as sound a rule as it may then have appeared. We Engineers (and I write in particular of the period when I had the honour to belong to the service) are only too conscious from hard experience that roads are regarded almost invariably by those, who hold the purse strings—and more often than not, by those in charge of local civil administration—as the eaters up of money, without due regard being paid to their economic value.

I believe that keen engineers will find themselves handicapped, even in the working out of development schemes initiated by themselves, if they leave out the administrative and financial considerations which apply. Their vision is thereby necessarily clouded and, to that important extent, their ability to impress their own reasoned enthusiasm successfully on the minds of those, who are in a position to help in implementing their schemes, lessened.

*"Consider India's Katcha Roads", reproduced on pages xxii to xxiii.

My own experience is that it is essential for rapid development to interest the local District Officers and that it is much easier to do this if a scheme, with all its implications, has first been prepared. Once enthuse the civil administration, having relieved it of the burden of working out at least financial costs and anticipated profits to the District at large, direct and indirect, a burden which in the nature of things the Engineer would, or should have worked out in a greater measure than the District Officer, to whom more than likely this aspect is an unaccustomed one and half the battle of rapid extensive development is won. The District Officer, when presented with a detailed scheme which rouses his enthusiasm, is more than likely, in my experience, to take it up as his own baby. This much-to-be-desired result is of extreme importance, when improvement of village roads is in question, as I shall later endeavour to show.

3 I see you advocate that the work of initial improvement of village roads might well form the province of the villager himself. Now the villager as a general rule is a poor man, faced at each successive harvest with the fear of total or partial failure of crops and without the financial means to meet without great difficulty the failure of even one harvest. With no experience to teach him that benefit will accrue to him therefrom, he very naturally will not embark on experiments which cost hard cash. This is too often put down to indifference; I do not agree, and believe, from wide experience, that my analysis of the cause is the right one as a general rule. So often have I seen new experiments tried without cost to the villager, which the latter has watched with keen interest tempered by the hard experience of the past; the value once proved to his satisfaction, he will then be prepared to carry out work on the lines of the long term experiment, having lost his fear of financial loss by the evidence of his eyes and through the working of his slow but far from stupid peasant mind.

The old time village road is as often as not a worn-down rutted track along the line of drainage The alignment and general straightening is an important factor in improvement. Further a greater width of land has frequently to be arranged for; this is expensive, if acquisition or voluntary sale is involved, but experience in the Peshawar District (and the Pathan is as strenuous a believer in the holding of land as anyone on the earth) showed that intelligent propaganda persuaded the majority of road side owners to permit the extra land needed to be used without compensation. It is here that the District Officer can help so largely, if his enthusiasm be aroused. It is of course always the old theme of enthusiasm plus the requisite personality.

The next step is the correct building up of the earth road with a correct camber and above all deep and well-thought-out side drainage. This last, I repeat, is all important. This is I believe can only be done efficiently, rapidly, and economically by machinery (graders, auto-patrols and so on) and I believe that this initial work must be done for the villagers and that it would be unreasonable to expect a village, or groups of villages, to embark on so scientific a work through their own resources. To carry out the work other than by the most efficient method possible would be, *in my view, throwing money away.*

Culverts should be made so that width between insides of wheel guards is at least 18 feet. The culverts themselves can be constructed economically with barrels of Tar or Bitumen cut in half and acting as forms for a concrete construction over them.

Work, carried out on a large scale, including writing off the cost of machinery, which at first sight appears heavy, should not cost more than Rs. 3000/- to Rs. 5000/- a mile This would also include bringing in clay or sand to make up a deficiency of either, though actually there are areas, where this is impossible without excessive cost, and which would require special treatment.

The value of earth roads, properly constructed, to the villager is immediately shown when the next harvest moves and this should prove a sufficient incentive to the villager to maintain the road once constructed; I agree entirely with you that the villager, who has considerable experience of the soil around his village, is the right man to carry this out and that it is reasonable to expect him to do so. For some time I do not doubt that the enthusiasm of local District officers, both Civil and Engineers, will be needed to keep the villager up to the mark about maintenance but I have little doubt that in the end maintenance by the villager himself will become a regular routine, welcomed by him owing to the value accruing.

I have purposely not gone into any minute engineering detail, which would take up a large space and would involve dealing with different methods as the nature of soil or climate varied. My purpose is to put forward an over-all idea only.

For the same reason I have omitted the obvious further development, as traffic increase justifies it, of improvement of surface by stabilisation and the final gradual development of a black surface.

4. In conclusion, although this subject has not been touched on in your address, may I suggest that the importance of roads in the economics of India is so great, and will I hope be increasingly so recognised, that to separate the "Buildings" and the "Roads" function of the P.W.D. has become worthy of serious consideration? "Buildings" are to a large extent in the province of architects; let there be one Chief Engineer by all means, under whom both "Buildings" and "Roads" should come, but beneath him let there be two entirely separate branches. "Roads" are too important for engineers, who should devote their entire minds to the problems connected with them, to be forced to turn their minds to bricks, drains, smoking chimneys and the thousand and one things, which every P.W.D. engineer knows only too well, are constantly arising to take his mind away from a subject which demands full time and a life time of thinking.

CONSIDER INDIA'S KATCHA ROADS

By G E. S

"Why Roads ?". Ask a hundred people at random this question, and the large majority, thinking only of their motor cars, will answer "to motor along". True this is an important function of roads especially in countries where tourist traffic forms an important item in economics or where railway connections are insufficiently widespread, but from an economic point of view the most important function is the carriage of agricultural produce, raw materials; and finished goods, and this article deals with this aspect

India is a country of great distances, of villages from which agricultural produce starts on its journey. The journey is by village road, subsidiary and main road to near market or to railway station India being preponderantly an agricultural country and likely to remain so for long, the disposal of the produce of its fields and forests is therefore of prime importance and the higher the price the producer can get, the more money he has for purchasing finished goods Selling price is normally fixed by factors outside the producer's control and the return to him is this price, at port or internal market, less cost of transport The importance of reducing the cost of transport is clear and every means that can be used economically to this end should be considered.

A Good Riding Surface.

Assuming that rail freight cannot be lowered saving can only be effected by improved roads The literally immense saving in transport cost that a good riding surface produces as compared with a bad one is rarely appreciated fully. Incredible as it may sound it has been actually proved that if twelve 30 cwt. lorries only travel daily over a water-bound macadam road instead of a katcha road, the saving in petrol, oil and wear and tear of vehicles and tyres aggregates in one year sufficient funds to pay for the cost of conversion The fact that still further saving is attained by converting the water-bound road into one treated with Tar, Bitumen, or Concrete is illustrated by tenders for carriage-contract over one route falling by 40 per cent after bituminous treatment of the surface. The reason for this is that a permanently good riding surface is essential and only by treatment can this be attained, under modern conditions of traffic.

Even the reconstruction of the ordinary village track into a well drained, well cambered "earth road" effects great savings. This process was adopted for some 200 miles of road in the Peshawar District and the result was a saving in cost of transport of 3 to 8 annas a maund between village and market or railway station although the distances did not exceed 20 miles

Improving "Katcha" Roads

These examples give an unanswerable argument in favour of the improvement of all katcha roads with the greatest speed possible and of

the creation of a good riding surface on roads of all descriptions which may form links in the chain of road and rail which carries produce of raw material in one direction and finished goods in the other. Nor must it be forgotten that road and rail are indeed links of the same chain and that co-ordination is of vital importance for the general prosperity of the country

As there are today some 60,000 miles of metalled roads and several times that length of katcha roads and as for full efficiency a great number of new roads are required, the problem at first sight may appear almost insurmountable owing to cost but provided certain principles are adhered to, it can be solved in a reasonably short term of years. The foremost principle is not to reconstruct a road to a higher standard than present traffic plus a reasonable addition, which the improved surface is likely to produce, justifies The second is that savings in maintenance cost of a given mile of road effected by treatment should be wholly used for improving other lengths of road and *not* towards financing work on the first mile. Not to follow this principle destroys all possibility of rapid improvement of the whole road net-work, unless immense sums of money are available, a condition which is certainly not existent in India to-day.

The fact that funds are not unlimited leads to the conclusion that initial cost must be the lowest possible consistent with economical maintenance as othewise fewer miles can be reconstructed annually and an unnecessary number of bad surfaced miles will remain to cause serious loss to the road user and so to keep up the cost of transport. It is sometimes argued that to spend 30,000 or 40,000 rupees in reconstructing a mile is sound because it is claimed the maintenance cost is reduced to small annual sums. This takes no account of the appalling losses that the road user will continue to have to carry for an unnecessary number of years owing to funds available being limited. There are certain roads, mainly in or in the vicinity of large cities and towns which have to be treated expensively because a cheaper form of construction will not stand up to the traffic, but probably the length of such roads does not exceed 2 per cent. while at least 95 per cent. of the roads in India can be treated for one-sixth of the cost. Supposing 3½ crores are available annually for reconstruction only, about 1,000 miles could be dealt with a year by the expensive method whereas 6,000 miles could be improved by the cheaper and all existing metalled roads could be dealt with in 10 years instead of 60 The latter, the author suggests, is practical economics and the former not. The more rapidly existing roads are improved the sooner can the much-needed additional roads be made.

Village Roads First.

Improve the village roads by reconstructing them as good "earth roads", to be later improved by gravelling and eventually by bituminous treatment as increased traffic dictates. Improve the surface of such existing metalled roads as form part of the main trade route by road and rail to port or internal consuming centre but only to the standard that the traffic justifies. Trade will increase, more vehicles will run, general revenues (including rail returns) will rise and India be on the way to increased prosperity.

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PAPER NO A-41

THE BROAD CLASSIFICATION OF TRAFFIC AND CONTRIBUTORY CAUSES OF WEAR AND TEAR OF ROADS

BY

SIR KENNETH MITCHELL, C I.E , A C G I , M INST C.E , A M.INSTT., I S E ,

Consulting Engineer to the Government of India (Roads), New Delhi.

PREFACE.

Ever since its first meeting, the Congress has been endeavouring, with mixed success, to standardise nomenclature, units of measurement, and other matters so as to evolve a common method or language in which members can express their specifications and state their experience. The Congress has succeeded in such matters as nomenclature and of expressing bituminous surfacing in pounds per hundred square feet instead of in square yards per gallon, tons per mile and so forth But it is still as common as not at our meetings to hear traffic described as "light" or "heavy", or whatever it may be when there may be widely differing ideas of what is meant by these expressions Moreover, even where actual figures are given, they are as often as not the totals and do not indicate the proportion of steel tyres. There have been Papers—notably that by Colonel Haig in 1936*—describing the method of conducting and applying the results of a traffic census, but the regular use of traffic statistics in every day work is often still lacking This is possibly partly because an elaborate traffic census is expensive, and counts by the road staff of doubtful accuracy, and partly because on any particular road the best specifications can often be evolved by experience on that or similar roads without absolute knowledge of the traffic intensity. There is also the fact that the scientific matching, so to speak, of specifications to traffic is seldom possible, the specification being dependent, not on the estimated total cost over a period of years under present and estimated traffic, but on the money available for the first outlay on improvement.

But if we are to benefit by the experience of others in different parts of the country and not rely on purely local evolution by severally following the same courses of trials and errors, some common method of stating the traffic and other contributory causes of wear is necessary

*"Traffic census and Road Diagrams" by Lt Col W de H. Haig. Proceedings of the Indian Roads Congress, Volume II, January 1936, page 40.

The Council of the Congress has for sometime had under consideration proposals to this end which have resulted in the method of classifications set out below It is a subject upon which there is great divergence of opinion, and at its last meeting the Council decided to leave it to writer to make the best compromise possible

The resulting proposal has been so severely criticised that it is useless to proceed without further discussion An example of the criticism is to the effect that the picture-formula is, from the nature of things, so incomplete as to mean nothing to the practical Engineer and would be incomprehensible to the lay mind The Road Engineer can, it is said, obtain complete information from properly kept road statistics and it is suggested that the Congress should standardise these statistics If it is impossible to secure acceptance of wholesale standardisation of road statistics, the proposed formula, based on these statistics is, it is alleged, useless

If that is how the proposal strikes any member, there must be something wrong

The proposals are based on the following propositions .—

(1) While the practice of taking careful traffic counts and recording accurate statistics should be encouraged by the Congress in every way, a division of traffic intensity into certain broad classes is at the present stage preferable to the use of absolute figures to the nearest, say, 50 tons giving a meretricious appearance of accuracy to a perennial variable.

(2) The most accurate statistics of total traffic, ignoring the proportions of different classes of traffic, may be as inaccurate and misleading as a broad classification in which the proportions are stated.

(3) The intensity of load per inch width of tyre (although there is nothing like uniform contact) may be as important a factor as a wide variation in total intensity.

The matter is presented to the Congress in the form of a Paper in the hope that by further discussion we may be able to approach nearer to a satisfactory system of comparable statistics

PROPOSED SCHEME OF CLASSIFICATION.

1. *Total intensity*

		Total Tons per 24 hrs.
Very light	— V. L.	0 to 200 tons.
Light	— L.	201 to 500 tons
Medium	— M.	501 to 1000 tons.
Heavy	— H.	1001 to 1500 tons.
Very heavy	— V. H	1501 and over.

2. *Classifications.*

There are three main classes of traffic, steel-tyred carts, other animal drawn vehicles and motor vehicles. The important classes are the first and the third Cycles can normally be neglected.

The proportion of each of the two important classes only need be stated. Thus if 'S' stands for steel-tyred carts (40 per cent of total daily tonnage) and 'M' for motor traffic (30 per cent) sufficient indication is given by "40 S" and "30 M".

3. *Unit Weights or Pressure Intensity.*

In the case of steel-tyred carts the principal factor is the loading of the steel tyre. The damage done by a bullock cart weighing two tons and having tyres two inches wide may, for various reasons, be greater than that done by a bullock cart weighing 1 ton and having tyres one inch wide—but not double. The weight per inch width of tyre (although it ignores the condition of the wheels and tyres and the diameter of the wheel, and hence the area of contact) is a more accurate factor. Any one in charge of a road ought to know both the laden weight and the tyre width of the general run of carts using it and, dividing one by the other, can readily state the load per inch width of tyre at, say, 750 pounds. The reference to 'S' thus becomes "40 S—750".

For the present, it is unnecessary to attempt in the general case to state the unit weight of motor vehicles or the proportions of transport vehicles and others That is a refinement that can come later. If there is any abnormal feature, such as a large proportion of 10-ton lorries, or a restriction of transport vehicles to 5 tons laden, these facts may be stated if considered necessary.

Thus we have $L \dfrac{40\ S\ 500}{30\ M}$

4. *Rain-fall and gradient*

These, the former in particular, have a considerable bearing on the wear and tear of certain road surfaces, and traffic figures alone do not complete the picture. Rainfall is to be indicated by the letter 'R' followed by the annual normal rainfall in inches—say 25 The Ruling Gradient may be stated as "Grad. 1 in.......".

5. *Width.*

On the whole for the general case of rural roads the total weight of traffic is a better indicator than the weight per yard width. As in the system of classifying roads, the metalled as well as the formation width should be stated in the case of metalled roads e. g., $\frac{12}{32}$ For an unmetalled road, it would be formation width only, say 40.

6. *Conclusions.*

These factors give a simple but informative formula.

Thus (a) for an unmetalled road A-B in an area of annual rainfall of 25 inches, with formation width 40 feet, ruling gradient 1 in 20, and carrying in 1940 a total traffic of 400 tons with 40 per cent of steel-tyred carts (with 500 pounds per inch width of tyre) and 30 per cent of motor traffic, the formula would be,

$$1940 \text{ Road A-B, W } 40,\ L \frac{40\ S - 500,}{30\ M}\ R25, \text{ Grad. 1 in 20.}$$

and (b) for a metalled road X-Y, in an area of annual rainfall of 30 inches

with a metalled width of 12 feet and formation width of 32 feet, ruling gradient 1 in 40, carrying in 1940 a total traffic of 1200 tons with 25 per cent steel-tyred carts, (load intensity 700 pounds per inch width of tyre) and 70 per cent motor traffic, the formula would be,

$$1940 \text{ Road X-Y, W } \frac{12}{32}, \text{ H} \frac{25 \text{ S} - 700,}{70 \text{ M}} \text{ R30, Grad 1 in 40}$$

If these are used in combination with the road classification formula, the reference to widths and gradient need not be repeated

Mr. Mahabir Prasad [Chairman] called upon Sir Kenneth to introduce his paper on "The Broad Classification of Traffic and contributory Causes of Wear and Tear of Roads". The above paper was taken as read.

Discussion.

Rai Saheb S.K. Ghose [Bihar] :—It would appear that Sir Kenneth Mitchell sketched out the compromise road picture-formula before he took over the immense task of co-ordinating the different forms of transports in India

If the immediate money available for outlay on improving any road is the only criterion, then with such Hobson's choice (as it apparently still obtains in most provinces, the roads piteously but silently crying for doles from provincial revenue, and not from capital which could easily provide the required money), the necessity for any laboured formula hardly arises.

The days of the bullock-cart [with steel tyres] are numbered, thanks to the advent of the producer-gas driven truck. It is learnt that 51 factories in India are producing different makes of such plants and that already 10,000 vehicles have been so converted and more are going to be transformed [already more than 20,000,000 gallons of petrol are said to have been saved]. The recent 12 days' tests of 25 three-ton Chevrolet lorries over a thosand mile course, have proved beyond doubt the reliability and economy of this revolutionary method of transport which works out to less than one pice per ton-mile.

If the Indian Roads Congress,. now, whole-heartedly declares war upon the steel-tyred bullock-cart, with public opinion as the solitary ally, it may be predicted that India will soon have the pleasure of killing the demon that creaks along our highways and by-ways, and low-cost soil roads will really be possible. There is no other way but to remove this canker. Palliatives will not do Other countries have done it. Why not India ?

However, coming back from the steel-tyred demon to the picture-formula, there are other factors also which might be introduced to make the mental panorama complete. Whether the road is soled or not makes a big difference under heavy traffic. The heaviest axle loads that can be allowed on the road is to be definitely stated as this will be limited by the strength of the bridges and culverts. The type of the road surface, whether metalled [sealed or unsealed], gravelled, or of stabilized soil, or kanker, might also be introduced in to the formula.

It is not very clear how the total annual rainfall or the ruling gradient of say a road 40 miles long can greatly affect its general capacity for carrying a particular intensity of traffic. In the region of steep gradients, e.g. in a hill section, the road will obviously require a better type of surface than in the rest of the road.

Perhaps, it need not be stated whether the road is all-weather or fair-weather, as we can safely take it for granted that the road being situated in India is but fair-weather.

The need for more and co-ordinated road-research and the collation and dissemination of research results obtained in other countries is keenly felt. "The Indian Roads" has ceased publication and the Congress is now 3-year variable ! If we could only help to revive the above institutions, they would remain for ever a fitting memorial to Sir Kenneth's genius and efforts in the cause of India's roads. Short-cut picture formulae might mislead us more than standardized road statistics, not unlike *KCl* and *KCN*.

PAPER NO. B-41.

A NOTE ON THE RECONSTRUCTION OF ROADS CARRIED OUT IN THE UNITED PROVINCES WITH SPECIAL REFERENCE TO EXPERIMENTS CARRIED OUT AND THE USE OF TRAFFIC STATISTICS

BY

MR. S. N. CHAKRAVARTI, M.B.E., I.S.E.,

Personal Assistant to Chief Engineer, Public Works Department, Buildings & Roads Branch, United Provinces, Lucknow.

The author has tried in this paper to place before the Congress a compilation of the records of some of the experiments made from time to time which have led the engineers of this Province to come to a more or less unanimous opinion as regards the behaviour of the different types of pavements.

Reconstruction of the roads of the United Provinces was undertaken on a large scale in the year 1924 out of a loan of rupees 144 lakhs, taken from the Government of India. Actual work was, however, started in 1926

In 1926, there were 3173 miles of Provincial roads out of which 1990 miles were kankar and the rest water-bound stone Tar and oil had been used only on a small scale as a remedy for dust nuisance.

The usual practice was to replace kankar with stone wherever traffic was heavy and this was sufficient until the motor traffic became appreciable.

The knowledge of the modern type of pavement was limited and the programme adopted consisted in

253 miles of reconstruction with stone or kankar metal,
31 miles of 6 inches cement concrete slab,
34 miles of bitumen mixed concrete, and
1 mile of bitumen spray.

It will be seen that surface dressing (then called bitumen spray), was given a low place and records show that it was considered only as a palliative against dust and was not supposed to extend the life of the water-bound coat of stone. The highest place was given to water-bound stone metal as is to be expected.

Actual work, however, differed greatly from the above, as the proposals were revised continuously in the light of experience gained from year to year. It was unfortunate that the programme had to be completed in five years and so a large amount of money was unknowingly wasted on pavements which did not stand up at all to expectations.

The following table gives the changes made with comparative costs and shows how the opinions varied from year to year.

Serial No.	Proposals.			Actual work.				Opinions in different years.
	Type	Miles	Cost per 100 sq ft.	Year	Type	Miles progressive total	Average cost per 100 sq.ft	
			Rs.				Rs.	
1	6″ cement concrete slab.	31	68/-	1926–27	Concrete 9″-6″-9″	1.25	58/-	Experimental length.
				1927–28	Concrete 9″-6″-9″	5 10	65/-	Surface standing well.
				1928–29	Concrete 9″-6″-9″ & 8″-6″-8″	14 10	66/-	There is opportunity of economy by reducing thickness by 3 or 4 inches. 6″–4″–6″ slab adopted as standard in 1931.
				1929–30	Concrete 9″-6″-9″ & 8″-6″-8″	18 80	64/-	
				1930–31	Concrete 9″-6″-9″ & 8″-6″-8″	32 25	64/-	
				1931–32	Concrete 9″-6″-9″ & 8″-6″-8″	34 88	64/-	
2	Asphaltic Macadam.	3	47/-	1926–27	Premix	10 10	55/-	Premix fit for all heavy traffic
				1927–28	Premix	10 25	55/-	Abandoned in 1929.
3	Bituminous grouted macadam.	31	61/-	1926–27	Grout	6 70	34/-	Fit for ordinary heavy traffic.
				1927–28	Grout	21 25	34/-	Too plastic. Ruts formed
				1928–29	Grout	32.00	34/-	Grout abandoned.
				1929–30	Semi-grout	36.60	22/-	Semi-grout adopted.
				1930–31	Semi-grout	37 85	22/-	
				1931–32	Semi-grout	40 10	22/-	Semi-grout abandoned.
4	Tar or Bituminous surface sprayed.	1	40/-	1926–27	Painted	7.75	6/-	Bitumen spray adopted.
				1927–28	Painted	67 10	6/-	Satisfactory.

Serial No.	Proposals.			Actual work.				Opinions in different years.
	Type	Miles	Cost per 100 sq ft.	Year	Type	Miles progressive total.	Average cost per 100 sq ft	
			Rs.				Rs.	
				1928–29	Painted.	119.80	6/-	Satisfactory
				1929–30	Painted.	203.00	6/-	Satisfactory.
				1930–31	Painted.	295.20	6/-	Satisfactory.
				1931–32	Painted.	353.60	6/-	Very satisfactory.
5	Water-bound	253	38/-	1926–27	Stone & Kankar	5		
				1927–28	Stone & Kankar	26		
				1928–29	Stone & Kankar	39		
				1929–30	Stone & Kankar	56		
				1930–31	Stone & Kankar	80		
				1931–32	Stone & Kankar	157		
	Total ..	319				596		*See footnote below

*During the years 1932 to 1936, the progress of reconstruction has been very slow on account of financial difficulties After 1936, the contribution from the Central Road Fund and the United Provinces Road Fund has enabled better progress to be made At the end of March 1941 the position is as below :—

Cement Concrete	173 miles
Bitumen Premixed and Grouted	66 miles
Painted	1113 miles.
Stone water-bound	477 miles.
Kankar water-bound	1639 miles

The laying of a large number of miles of cement concrete has been possible due to the success of the experiments carried out with thin slabs less than 6 inches.

Premix Premix and asphaltic concrete pavements 2½ inches to 3 inches thick were laid in nearly 10 miles at a cost of nearly rupees 9 lakhs in 1926–27 These pavements showed signs of rutting under concentrated bullock cart traffic due to the presence of excessive bitumen and, within three years, some of the miles had to be reconstructed and others ripped up and re-surfaced with cement concrete

Mr P H Tillard, the then Chief Engineer, gave the opinion in his report in March 1929 that this form of surface is not suited to concentrated cart traffic and at the same time requires a considerable amount of light traffic to keep it in condition Its cost makes it almost prohibitive when only medium heavy traffic has to be considered.

Grout Fortythree miles of grouted pavements were also laid during 1926 to 1932 at the rate of nearly rupees forty per hundred square feet These also showed, although to a small extent, the same defect as the Premix A reduction of the bitumen content from 194 pounds to 167 pounds per 100 square feet made some improvement but the results did not justify the high cost and this kind of pavement was given up in 1930

Grouting was considered suitable only for sections with medium traffic and its high cost did not appear to justify its use where a water-bound and painted road met the needs.

Semi-grout A new specification known as the Semi-grout was then tried. This consisted in grouting a partially consolidated surface of stone with 167 pounds of bitumen per 100 square feet The extra cost was, however, not considered justified even in this case as compared with surface dressing which had by now established its usefulness

Painting To start with, surface painting was restricted to places with motor traffic only, to get over the dust nuisance. But after a few miles had been laid and results watched for a couple of years, its efficacy was demonstrated and by 1931–32, 353 miles had been painted with various bituminous products

With the failure of premixed pavements, more attention was paid to painting and to be able to compare the life of surface painting, many experimental lengths were laid using various materials

In one coat work, Trinidad asphalt did not stand up as well as hot bitumens like Spramex, Socony 105, etc. Emulsion also did not generally give the same life A cut-back known as Mexaco was extensively tried as first coat but it was found that the second bitumen coat did not have any better life

In two coat works, priming coats of Mexaco (a cut-back), Ormul (an emulsion) and Tar No 2 were tried. The first two were not considered to improve the surfaces and their use was given up. In all two coat works, Tar No. 2 is now used for the first coat and the second coat of hot bitumen is applied after one year.

The quantity and the size of the grit was varied to determine what would give the best results, but these were too conflicting to lead to any definite conclusions. It was, however, decided in 1937 that three-fourths inch grit gives the best results and it was adopted for the standard specification of the United Provinces.

For one coat work, the quantity of bitumen now in use is, on an average, 44 pounds per hundred square feet. For two coat works, forty four pounds per hundred square feet of Tar No 2 followed by a bitumen coat of 24 pounds per hundred square feet is the standard.

For repainting, the consensus of opinion is that the minimum quantity required to cover the surface should be used. The standard specifications followed in the United Provinces are attached (Appendix I, page 17).

In some miles, Tar has also been used as a second coat. These portions had, however, to be repainted every second year and the annual cost of maintenance works out to more than that for the portions with bitumen for the second coat.

Single coat work in the western districts like Agra and Meerut have lasted very well, while in the eastern districts, this has not given as good a life. This is possibly due to

(i) the varying affinity of different kinds of grit to bitumen,

(ii) climate, and also

(iii) the difference in the percentage of steel-tyred traffic to the total volume of traffic.

A statement of the results of the affinity tests on grit obtained from different quarries in the United Provinces is appended (Appendix II, facing page 20). Bayana grit which is used in the Agra district has a place higher in the list than Bharatkup which is generally used in Cawnpore and Allahabad districts and this may account partly for the better behaviour of the painted roads in that district. Results in the Meerut district are equally good and Delhi grit is used there. No test of the affinity was unfortunately made of this grit. It will, however, be seen that Moth grit (No. 16 in the list) which is higher on the list than Bayana, is softer and crushes under traffic. It seems, therefore, doubtful if affinity alone can be the deciding factor. Some more experiments and tests appear to be necessary in this direction.

Painting over Kankar. Kankar being very cheap in some areas of the Province where harder stone is not readily available, painting on kankar was also tried with various materials. Surface painting with Liquid Asphalt of various grades, hot bitumen like Spramex, and with emulsions etc. [as also 1-inch carpet of Bitumul Premix] were each tried in experimental lengths. None of them, however, can be called a success as they showed patches within a year of their construction and efforts in this direction have for the present been stopped.

Various other experimental lengths were laid most of which did not compare favourably with ordinary surface dressing of Bitumen or Tar. Some of them are described below.

Liquid Asphalt. Liquid Asphalt was tried as a priming coat and also as a surface dressing. For surface dressing, only 20 pounds were used per hundred square feet. Results have been unsatisfactory (Items 4,5 and 9 of Appendix III, pages 21 to 23).

Socofix Carpet. A thin carpet to serve as surface dressing was tried with this material. A priming coat of 11 pounds per hundred square feet followed by a layer of premixed grit one-fourth inch to three-fourths inch was laid. The surface failed within a year (Item 6 of Appendix III, page 23).

Socosol. This was mixed with Socony Asphalt to obtain a better spread of the bitumen in surface dressing. It was certainly possible to apply the bitumen at the rate of 15 pounds per hundred square feet, but the result did not justify the extra cost.

Shelspra. It is a Burmah-Shell product. Three-fourths inch and one inch carpets have been laid. The material has also been used as a surface dressing of two coats laid at an interval of one month. The experimental lengths were laid in November 1938. While the carpets are standing well, the surface dressing has worn out.

A list of some of the experiments with short notes on each is attached (Appendix III, page 21). In the author's opinion ordinary painting with hot bitumen or tar has given consistently good results.

Concrete. Concrete pavements found a place in the first programme made out in 1921. The specification was to lay a slab 6 inches thick over lime concrete base 6 inches. The first experimental length laid was, however, a slab 6 inches thick, thickened at the edges to 9 inches with butt joints inclined at 60 degrees to the longitudinal axis of the road. The alternate bay system was adopted.

The success of the experiment led to the adoption of this type in preference to Premix, Asphalted concrete or Grouted macadam and 35 miles of cement concrete pavements were laid between 1926 and 1932.

The average cost of concrete pavement of section 9"-6"-9" was Rs 63/10/- per hundred square feet, prohibitive for general adoption. Many experimental lengths of concrete pavement were laid to different thicknesses as detailed in Appendix IV, page 30. The aim had been—

(a) To gradually reduce the thickness of the concrete slab to make it economical;

(b) To examine the effect of reinforcement in the strength of the slabs;

(c) To examine the effect, if any, of having thickened edges; and

(d) To reduce the cost of laying and the period of operation by adoption of the continuous method.

The reduction in thickness was made gradually.* The success of the small length of 6"-4"-6" slab laid in 1926 encouraged the laying of thin slabs and, in 1929, an experimental length of 844 square yards of 4½ inch slab was laid. By 1931, 6"-4"-6" was the standard and 4 inches thick slab was laid as an experiment. In 1935, the thickness had been reduced to 3"-2"-3" but 5½"-3½" 5½" slabs were laid in long lengths. By 1939, the 3-inch slab of uniform thickness had been adopted as the standard for reconstruction of existing water-bound roads in rural areas The cost has been reduced from Rs. 63/10/- to nearly Rs. 22/- per hundred square feet.

Reinforcement was not found to materially improve the strength and wear of the slabs and is considered unnecessary in cases of reconstruction where there is an old road of sufficient thickness to serve as foundation.

The omission of the thickened edge has not also weakened the pavement to any great extent nor is the extra cost of laying on the alternate bay system justified. Nearly all the experimental lengths have stood up to the test very well indeed, with the result that thin concrete slab of uniform thickness of 3 inches is now considered to be a satisfactory pavement to take all the ordinary traffic that rural roads in the United Provinces carry. As thinner pavements of section 3"-2"-3", laid in 1935, have already had a life of 6 years without showing signs of much wear, there is no reason to doubt that a 3-inch slab would have a life of at least 15 years which is sufficient for it to pay its way on economic considerations.

The average cost of laying such a slab is about Rs. 26/- per hundred square feet including the subgrade.

It must be added, however, that these thin slabs have all been laid on old macadam roads having a crust of at least 6 inches thickness and the concrete slab is bonded with the subgrade by omitting the insulation layer. Unusually high expansion has been observed in the thin slabs laid over an insulation layer on the Ghaziabad-Bulandshahr road† and about half a dozen bursts occur each year accompanied by a raising of the slabs at joints, bending and ultimate crushing of the portion affected. The insulation layer between the subgrade and the slab is not, therefore, now given in the case of thin slabs of 3-inch thickness.

The effect of the bonding with the subgrade has, however, not yet been fully demonstrated and measurements of actual expansion and contraction in insulated and un-insulated slabs are being made to determine this. None of the slabs laid on this system has as yet shown the unusual expansion trouble which is experienced on the Ghaziabad-Bulandshahr road and the measurements of expansion taken up to date

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* *Vide* "Evolution of the thin Concrete Road in the United Provinces" by W. F. Walker, proceedings of the Indian Roads Congress, Volume VI, Paper No. A-39.

† *Vide* Proceedings of the Indian Roads Congress, Volume VII, Part 2, Pages 248-249.

show that there is a definite resisting effect when the variation exceeds a certain limit.

In the alternate bay system, the contraction of the slab while setting was considered ample to provide for all the expansion which may occur with the rise of temperature. This may have been true in the case of thick slabs but, for thin slabs, expansion joints 3/8" thick are now given between every slab

Roller-crete, Gunite, etc. Some experimental lengths were laid to different specifications known as Roller-crete, Colloidal Cement Grouted Macadam and Gunite They did not, however, prove a success Short specifications of these are given in Appendix IV, page 31.

Vibrated Concrete. Vibrated concrete has also been laid in a few miles on the Lucknow-Jhansi Road. Compression tests show the following results

No	Mix	Slab	Situation	Crushing load in tons per sq. inch.	Crushing load in lbs per sq. inch.
1	1 3 6 hand-tamped	3"	Mile 60	2 36	5286
2	1 3.6 vibrated	3"	Mile 60	2.38	5331
3	1 3.6 vibrated	3"	Mile 60	2 22	4973
4	1 2·4 hand-tamped	3"	Mile 74	2 92	6541
5	1 2·4 vibrated and hand-tamped	3"	Mile 73	3 21	7190
6	1.2 4 vibrated	3"	Mile 73	3 41	7638
7.	1·2½ 4½ vibrated and hand-tamped	3"	Mile 73	2 89	6478

It will be seen that vibrated concrete of 1 2·4 mix was about 15% stronger than the hand-tamped one, though in the case of 1 3.6 mix, the gain in strength was negligible and actually in one case there was loss, *vide* item 3 of the above statement. The reason is not very apparent, but may be due to the difficulty of obtaining uniform concrete with a lean mix and a probable loss of strength resulting from the cement working up to the top in the case of vibrated concrete

The extra cost of working the vibrator unfortunately absorbed the saving in cement and so the method has not been widely adopted.

Results. The results of all the experiments carried out during the last 15 years have given the general opinion that the alternatives of modern types of pavement lie between 3 inches cement concrete and painting for all roads carrying ordinary mixed traffic provided the intensity of individual loads is not very high.

The choice of the types and selection of the miles for reconstruction will depend on economical considerations and traffic condition of the particular miles.

Economical consideration. A formula for the annual cost of the different types of surfaces devised by Mr. L. B Gilbert, I. S. E , Chief Engineer of the United Provinces is given in Appendix V, page 36. Interest has been omitted from the calculations. The graphs attached show that a 3-inch thick concrete pavement with an average life of 15 years where metal, suitable for concrete work, costs Rs. 25 per 100 cubic feet,

(i) costs, in the long run, only as much as a 4½" thick kankar coat if kankar costs Rs. 10/- per 100 cft. and lasts for 3 years,

(ii) is definitely cheaper than 4½ inches thick kankar coat if the life of the latter is 2 to 2½ years, and

(iii) costs, in the long run, only as much as a surface-painted 4½" thick water-bound stone macadam, if renewals of metal and surface repainting are each necessary once in every 15 and 3 years respectively.

Traffic consideration. Lt. Col. W. deH. Haig, D.S.O., R.E., in his Paper No. 16 read before the Indian Roads Congress* of 1936, had suggested that it would be necessary to find a "yard stick" so that the choice of the type should not depend on the opinions of individual officers (which are likely to vary considerably) but be directed by a consideration of the traffic statistics of a mile

In accordance with Col. Haig's suggestions, a special census was taken in which steel-tyred, and wooden-tyred carts were counted separately. The results are tabulated in Appendix VI, page 41. Unfortunately they are so divergent as to make it impossible for any definite conclusions to be drawn.

While there is no doubt of the increased wear by narrow steel tyres on painted roads, the statistics collected do not admit of any relation being established between the damage done by steel tyres and wooden tyres.

The "yard stick" has not been found but it is necessary to form a general idea at least of the maximum limit of traffic which each type of surface can take, so that reconstruction programmes could be framed on more definite principles.

* "Traffic Census & Roads Diagrams" by Lt. Col. W. deH. Haig, D.S.O., Proceedings of the Indian Roads Congress, Volume II, page 44.

As far as this Province is concerned, there are only three surfaces to be considered, namely, (i) Kankar metal coat, (ii) Surface paint, and (iii) 3-inch cement concrete A comparison of the annual cost of the three types have shown that, to be economical,

(i) Kankar must have a life of at least 3 years.

(ii) Painting must have a life of more than 3 years, to be more economical than concrete.

(iii) Concrete must last 15 years.

(i) In this Province, it is considered that Kankar surfaces with a life of 3 years would be economical for a total mixed traffic up to 500 tons a day.

(ii) In the case of painted surfaces, however, opinions vary. Mr Wiggin, Executive Engineer, considers this type suitable for a "cart traffic up to 800 tons per day," while Messrs Hatfield, Mukerji, Bisht and Sri Narain, Executive Engineers, consider 500 tons as the limit. In addition to this cart traffic, painted surfaces could take any amount of pneumatic-tyred traffic.

These figures are for 12 feet width.

An extract from the history sheets of the reconstructed miles in Cawnpore, Agra and Meerut divisions is given below. The miles chosen are those for which records for at least two renewals of surface paint are available.

Serial No.	Traffic in tons		Name of Road.	Mile	Year of re-paint	Life (years).	Remarks
	Carts	Total					
			Agra and Meerut divisions.				
1	671	1222	Bombay Delhi Rd	749	1927, 1929, 1931, 1939	4	Two coat work
2	671	1222	Bombay Delhi Rd	751	1931, 1936	5	
3	485	1430	Delhi Mussoorie Rd	73	1936, 1939	3	
4	485	1430	Delhi Mussoorie Rd.	74	1936, 1937, 1939	2	Two coat work.
5	500	1000	Bombay Delhi Rd	784	1929, 1931, 1936	3½	
6	436	940	Bombay Delhi Rd	755	1928, 1935, 1939	5½	
7	436	940	Bombay Delhi Rd	756	1927, 1935, 1937	5	
8	610	810	Bareilly Muttra Rd.	107	1931 1937	6	
9	410	545	Bareilly Muttra Rd	100	1932, 1938	6	
10	227	635	Delhi Mussoorie Rd.	79	1931, 1935, 1938	3½	
11	227	635	Delhi Mussoorie Rd	80	1931, 1935 1938	3½	
12	235	643	Delhi Mussoorie Rd	83	1935, 1937	2	
13	235	643	Delhi Mussoorie Rd	86	1931, 1934, 1937	3	
14	110	520	Delhi Mussoorie Rd	107	1933, 1938	5	
15	110	520	Delhi Mussoorie Rd	112	1933, 1939	6	
16	133	537	Delhi Mussoorie Rd	120	1930, 1933, 1939	4½	

Serial No.	Traffic in tons. Carts	Total	Name of Road.	Mile	Year of re-paint.	Life (years).	Remarks
			Cawnpore division.				
17	1150	1261	Cawnpore Hamirpur Road.	12	1928, 1929, 1930, Reconstructed 1933, 1934, 1937, 1939	1 2	
18	1150	1261	Cawnpore Hamirpur Road.	13	1928, 1930, 1933. Reconstructed 1935, 1936, 1939	3 2	Two coat work.
19	1150	1261	Cawnpore Hamirpur Road.	14	1928, 1929, 1931. Reconstructed 1933, 1934, 1937, 1939	2½ 2	
20	1150	1261	Cawnpore Hamirpur Road.	11	1928, 1932, 1935, 1937, 1939	2¾	
21	663	987	Grand Trunk Rd	629	1929, 1932, 1933, 1939	3 3	
22	663	987	Grand Trunk Rd.	632	1927, 1930, 1933, 1935. Reconstructed 1938, 1939, 1941	2 6 1½	
23	663	987	Grand Trunk Rd	633	1927, 1930, 1933, 1936. Reconstructed 1938, 1939, 1940	2 1	
24	856	956	Grand Trunk Rd	608	1931, 1934, 1939	4	
25	768	879	Lucknow Jhansi Road	60	1929, 1932, 1935		Changed to concrete.
26	768	879	Lucknow Jhansi Road.	65	1931, 1934, 1936, 1938	1·7	
27	475	587	Cawnpore Hamirpur Saugor Rd.	16	1935, 1936, 1939,	2	Two coat work.
28	475	587	Cawnpore Hamirpur Saugor Rd.	21	1934, 1935, 1937, 1940	2½	
29	382	480	Grand Trunk Rd	596	1928, 1934, 1938	5	
30	382	480	Grand Trunk Rd.	599	1927, 1933, 1938	5½	
31	382	480	Grand Trunk Rd.	598	1932, 1938	6	
32	382	480	Grand Trunk Rd.	602	1927, 1930, 1934	3½	

It will be seen that for a total traffic of nearly 1200 tons, surface paint has a life of 4 to 5 years in Agra (S. Nos. 1 & 2) while in Cawnpore it has only 2 to 3 years' life (S. Nos. 17 to 20). For 800 to 1000 tons, this life in Agra and Meerut Divisions is between 3·5 to 6 while in Cawnpore it is only 2 to 4. It is only when cart traffic is less than 500 tons (as in serials 29 to 32) that a life of more than 3 years has been reached in all the three divisions.

The specifications followed in the three Divisions were similar except that Delhi and Bayana grit were used in Agra and Meerut Divisions, while Bharatkup was used in Cawnpore The results of affinity tests show that Bayana and Delhi grit have a higher place than Bharatkup The better results in Meerut and Agra Divisions may be partly due to this fact, but the main reason seems to be the lower percentage in these Divisions, of cart traffic which is only 30 to 50 per cent as against 75 to 90 per cent in Cawnpore Division It would probably not be far wrong to assume that the cart traffic is the criterion in the case of painted surfaces, and the actual results tabulated above show that generally 500 to 600 tons of cart traffic is the maximum which a painted surface may be assumed to take, to have a life of 3 years Of miles mentioned in serials 17, 18, 19, 22 and 23, those having a cart traffic of 1150 tons had to be reconstructed after 5 to 7 years while those with 663 tons had to be reconstructed after 11 years It is clear that apart from re-painting, the water-bound coat also does not have the full accepted life of 15 years for a cart traffic of above 600 tons.

Concrete pavements laid in 1925 and 1926 have not shown any signs of disintegration and the assumption of a life of 15 years is not unwarranted.

The general principles which are followed in the United Provinces in making out a reconstruction programme may be summarised below:

1. All kankar miles carrying more than 500 tons of total mixed traffic per day over a 12 feet width should be reconstructed with better types
2. A painted surface will be economical only if the intensity of cart traffic does not exceed 500 tons per day on a 12 feet width of road.
3. For all roads carrying heavier than 500 tons of cart traffic per day on a 12 feet width of road, concrete should be adopted

During the War period, when the price of bitumen is bound to remain high, 3-inch concrete would be economical for all miles carrying above 500 tons of total traffic per day.

Having arrived at the above conclusion, the diagrammatic chart described by Col. Haig in his paper referred to above comes in very handy for the preparation of a reconstruction programme. A sample chart of the Agra division is attached (Appendix VII, facing page 42,) which shows the traffic figures as counted in 1939 in different colours. The firm lines represent the existing surfaces

Kankar miles carrying more than 500 tons per day can easily be picked out from the chart and included in a long term reconstruction programme, priority being given according to the importance of the road.

A reconstruction programme of the Grand Trunk Road drawn upon the above lines has recently been sanctioned and all *kankar* miles carrying over 500 tons of traffic per day have been included in this programme. The total number of miles for reconstruction is 101 and the estimated cost is Rs 17 22 lakhs

The programme for the year 1941-42 provides for 3 inches cement concrete on 52 miles of the Grand Trunk Road and 21 miles of the Lucknow Bareilly Road.

APPENDIX I

SHORT SPECIFICATIONS

PREMIX.

The wearing coat of premixed bituminous macadam, was 3 inches loose ($2\frac{1}{2}$ inches consolidated) thickness.

The following materials were used :—

(i) Asphalt cement.—

100 parts by weight of Trinidad Refined Asphalt.
15 Parts by weight of Flux oil.

(ii) Metal.—

Delhi quartzite broken to $\frac{1}{2}$-inch gauge

(iii) Filler.—

Coarse and fine sands two parts to one by volume.

(iv) Mixture.—

Each boxful of the above materials mixed by the plant consisted of the following :—

Metal	..	..	312 lbs.
Sand	..	..	60 lbs.
Asphalt cement		..	28 lbs.
		Total	400 lbs.

For the sealing coat of both the premixed bituminous macadam and bituminous grouted macadam the following materials were used :—

(i) Asphalt cement.—

100 parts by weight of Trinidad Refined Asphalt.
40 parts by weight of Flux oil.

(ii) Grit.—

Of such a gauge that all passed a $\frac{1}{2}$-inch diameter circular opening and was retained on a 10 mesh screen.

After laying, it was sealed with asphalt cement, gritted and rolled ; 3·3 cubic feet of grit was used per 100 square feet. The asphalt cement was used at temperatures between 325 to 375 degrees Fahrenheit and mixing was carried out by machinery.

GROUT.

Upon the existing metalled surface, cleaned of all dust and dirt, 3 to $3\frac{1}{2}$ inches stone ballast, $2\frac{1}{4}$ inch gauge, was laid dry and hand-packed. No dry rolling was done. The surface was marked off in areas with strings between straight edges and 167 pounds of asphalt per 100 square feet were used. $\frac{3}{4}$ to $\frac{1}{2}$-inch gauge stone metal chips were

immediately spread on the surface and the whole was thoroughly consolidated with a 12-ton roller followed by a 15-ton roller. The surface was then well brushed and cleaned and the seal coat was applied without allowing traffic on the grouted surface The surface was marked off and the asphaltic cement was spread at the rate of 34 to 45 pounds per 100 square feet. ⅜-inch to ⅛-inch gauge stone grit was immediately spread over the surface and again well-rolled. The bitumen heated to 325 to 375 degrees Fahrenheit was then poured over the surface in hand-pouring cans both for grout and seal coat.

SEMI-GROUT

After draining the existing metalled surface, of all dust, etc. 3½″ loose stone metal, 2 to 2½-inches gauge, was laid, hand-packed and rolled dry till the roller made no further impression. The surface was marked into rectangles and a mixture of heated asphalt or bitumen was poured by means of wide mouthed pouring cans, at the rate of 181 pounds per hundred square feet Intermediate stone ¾-inch gauge was immediately spread at the rate of 6.67 cubic feet per hundred square feet and well rolled with a 15-ton roller. The surface was then again swept and seal coat of heated mixture of asphalt or bitumen was applied at the rate of 54 pounds per hundred square feet ¼-inch to ⅛-inch size grit was then spread well over the surface and rolled with a 15-ton roller

PAINTING.

Before the application of paint, whether this is to be of tar, cut-back or emulsion, the surface of the road was thoroughly cleaned of all caked mud and cow dung with stiff brooms or, if necessary, with wire brushes, swept with bass brooms followed by housemaid's brushes of medium softness Finally all dust was blown off by means of gunny bags or, if available, hand or mechanical blowers. Only that amount of surface was broomed and brushed as could be painted the same day and the final cleaning by blowing did not precede the application of paint by more than half an hour

During the cleaning and while painting, the berms and pattries were kept thoroughly watered When an emulsion was used for the first coat, the surface of the road was well soaked with water before the application of the paint but, at the time painting was commenced, there was no free water on the surface and the road was in a condition described as "thoroughly damp"

When the paint was applied by pouring, endeavours were made to restrict the quantities used per hundred square feet to those given below.—

First coat with Tar—from 41 to 45 pounds

First coat with emulsion—from 33 to 39 pounds

First coat with cut-back—about 30 pounds.

Second coat with hot bitumen—from 23 to 29 pounds.

Second coat with Tar No. 2—from 22 to 28 pounds.

A hot paint was heated to a temperature not higher than that specified by the makers, in boilers provided with suitable thermometers. The material was not poured on to the heated surface of the boiler lest it be burnt.

The paint was applied to the road surface with specially constructed wide-mouthed pouring cans of known capacity. To obtain correct and even distribution of paint the road surface was divided into rectangles of known area each suitable for the contents of one pouring can and the paint then poured longitudinally and brushed evenly over the surface with bass brooms Brushing was always done from the sides towards the crown. Brooms were cleaned at the end of the day's work.

As soon as the paint had been spread in the case of hot paint, or as soon as the paint commences to break down in the case of an emulsion, the grit was spread on the surface.

The quantity of grit to be used per hundred square feet shall be not less than the following :—

First coat with Tar emulsion or cut-back—4.4 cubic feet.

Second coat with hot bitumen or Tar—2.2 cubic feet.

After the grit had been spread evenly over the surface, it was rolled with the lightest roller available. Rolling was continued only sufficiently to press the grit into the painting material and to fill the interstices of the metal in the case of the first coat.

The second coat of paint was applied as soon as the first coat had reached its "optimum" condition, i. e., when the paint had hardened, the surface had become smooth, and exhibited a mosaic appearance with all loose grit absorbed. The period which elapsed between the first and second coats of paint depended on the volume of traffic and on the material used for painting. Tar was allowed to harden before being re-painted with bitumen, as otherwise it remained as a soft layer under the relatively hard bitumen and the road surface soon became uneven.

CEMENT CONCRETE SLABS.

The existing metalled crust, if less than 6 inches thick, was given a new coat of metal sufficient to make the thickness of the subgrade at least 6 inches. Otherwise, the surface was left undisturbed and only scarified and 2 inches of additional metal given to get the profile of the underside of the slab.

All thin slabs were anchored to the subgrade which was brushed to remove all fine and loose particles of metal.

The mix was as follows
1 bag of Portland cement.
2 4 cubic feet of fine aggregate.
4 8 cubic feet of coarse aggregate
5 to 6 gallons of water according to temperature and weather
Hand mixing was resorted to only in emergency.

The bays were generally 33 feet long and were laid continuously Expansion joints not less than ½" were provided between each bay and filled with bitumen before opening the road to traffic.

Curing was done by covering the slab with a six-inch layer of earth and kept saturated with water for 21 days

APPENDIX III.

Short notes on the experiments on Bitumen and Tar roads.

No.	Name of experiments	Traffic intensity in tons	Particulars	Remarks
1	One inch Bitumul premix carpet on old kankar surface.	750—1000	The 1-inch thick carpet was laid in two layers, the lower layer consisting of 7 cubic feet, $\frac{3}{4}$-inch to $\frac{1}{4}$-inch Delhi stone chips premixed with 4 gallons of emulsion and the upper one of 3 cubic feet of 3/8 inch Delhi stone chipping premixed with 2 gallons of the emulsion. The carpet was laid to a camber and rolled with a 7-ton Diesel roller after 6 hours and blinded with 1/8-inch stone chips at 1 cubic foot per hundred square feet and the road opened to traffic the third day. The cost came to Rs 11/-per hundred square feet.	This was laid in February 1938. After 6 months, knobs of old surface began to show and patches found here and there. A re-seal coat with Bitumuls was applied in 1939 which was in fair condition till December 1940.
2	Liquid Asphalt painted on kankar surface.	500—700	This was applied at two different places at the rate of 20 pounds and 40 pounds per hundred square feet respectively.	It had been worn out within a year.
3	Painting kankar with emulsion.	250—500	Socony emulsion No. 6 was tried but it began to wear out after 6 months.	It was found that emulsions used on kankar do not penetrate.
4	Liquid Asphalt No. 2 tried to anchor	500—700	The surface was cleaned and Liquid Asphalt applied at the rate of 22 pounds per hundred square	The surface began to break in the rains of cold

No.	Name of experiments	Traffic intensity in tons	Particulars	Remarks
	down a hot bitumen paint coat to the water-bound macadam underneath.		feet. Seven hours later, a 3/8-inch layer of coarse sand was laid and road opened to traffic. Next day, more sand was applied where it had peeled off. After 20 days, Socony Asphalt grade 105 was applied at 28 pounds with Delhi grit at 4 2 cubic feet per 100 square feet Cost came to Rs. 4/4/- per hundred square feet This was done in 1935.	weather in January 1937. In June 1937 the whole surface had to be scraped off and painted with Tar. Life 2 years.
5	Liquid Asphalt painted over water-bound Gaya stone	250—500	This was applied with a perforated can to cover evenly at the rate of 20 pounds per hundred square feet and left over to penetrate for 24 hours and then covered with sand at 3 cubic feet per hundred square feet within a fortnight	The length covered with grit and sand presented a coat which was too brittle and got broken like sand on being compressed. Where Gaya and Ganges sands were applied, the lengths appeared as if no painting was ever done and the surface was such as if it was blackened only. Neither the interstices had been adequately filled with paint nor was there any covering of paint over the metal.

No.	Name of experiments	Traffic intensity in tons	Particulars	Remarks
6	Premix Socofix.	750—1000	A priming coat of Socofix at 11 pounds per hundred square feet was given and allowed to soak for 4 hours. Premix of Haldwani bajri [illegible]-inch to [illegible]-inch and Socofix at 30 pounds per hundred square feet was applied on the painted surface. The surface was then rolled and sand sprinkled where it stuck to the roller wheels. Cost worked out to Rs. 6/2/6 per hundred square feet.	Failure. This was done in 1937. It had to be repainted in 1938 as it was very soft to wear.
7	Repainting with Socony emulsion No. 6 over Trinidad Refined Asphalt.	over 1000	The quantity of emulsion used per hundred square feet was 9 pounds which is equivalent to 6 pounds of bitumen.	Failure. The surface remained in good order for 4 months only. Much service could not be expected from such thin coats
8	Socosol.	over 1000	With a view to obtain a better spread of bitumen, Socosol was added to Socony asphalt, grade 105, in a proportion of 5 per cent of Socosol to 95 per cent of asphalt heated to 380 degrees Fahrenheit.	The spreading was found easier and the bitumen could be applied at 15 pounds per hundred square feet. The results were about the same as with the use of Spramex, 180 to 200, penetration. It only adds to cost.
9	Liquid Asphalt No. 2 as first coat.	0—250	Liquid asphalt No. 2 was used at 26 pounds with 2 cubic feet of grit per hundred square feet for the	The experiment is incomplete as yet but the

No.	Name of experiments	Traffic intensity in tons	Particulars	Remarks
	and Socony asphalt 105, as second coat		first coat and Socony grade 105 used at 25 pounds with 4·1 cubic feet of grit per hundred square feet for the second coat The surface was treated in 1938	surface so treated is standing well.
10	Socony asphalt compared to Spramex.	500—750	Socony asphalt was applied as initial coat using 51 pounds of bitumen and 4·3 cubic feet of grit per hundred square feet Spramex was applied at the rate of 52 pounds with 4·5 cubic feet of grit per hundred square feet The cost of the former was Rs 4/10 per hundred square feet while that of latter Rs 4/11 No remarkable difference in the behaviour of the two was noticed	No difference.
11	Tar and Bitumen grout for curves.	250—500	Tar and Spramex grout were respectively tried on curves but Tar, due to its inferior adhesive properties, proved a failure within a month of its application	Failure It was breaking under the traffic. Patches done with Spramex grout, however, held on well till the whole surface was repainted with Spramex after 9 months of the first coat
12	Bitumuls patching	0—250	Brush out dirt, fill the cavity with hard stone metal 1½ inches to ¼-inch gauge, roll or ram until compacted Apply Bitumul H X at 10 pounds per cubic feet of new metal and paint 6 inches round the patch to ensure proper bond. Cover the patch with	This behaved like Colas or Tar patch but was found too costly. The cost came to Rs 14/8 per hundred square feet of

No.	Name of experiments	Traffic intensity in tons	Particulars	Remarks
			3/8-inch to 10 mesh stone chips	the patched area.
13	Bitumen strip roads.	500—750	Two strips each 2 feet wide, 2 feet 10 inches between internal edges and equi-distant from the centre line of the road were treated with Spramex. Paint was used at 52 pounds with 4 cubic feet of grit per hundred square feet.	The unpainted portion between the strips gives some trouble. The experiment is current.
14	Non-skid painted surface.	500—750	Heated chips were spread on the slippery painted surface and rolled with a view to embed them into the old painted surface.	Failure. The old paint had not the required affinity for the chips and therefore, the chips came out after rolling. Generally, the surface became slippery when it is hard and the grit did not adhere or penetrate into the hard surface. The grit got crushed
15	Light rolling of grit on bituminous roads	500—750	The idea was to closely pack the grit before being rolled with a heavy roller so as to get less crushing. Light mechanical rollers were tried to roll the grit before pressing with a 8 or 10-ton roller.	The surface so treated did not show any marked difference compared to the surface rolled with a 8 or 10-ton roller only.
16	Limpet brand	over 1000	The asphalt was cooled according to makers'	The experimental

No.	Name of experiments	Traffic intensity in tons.	Particulars	Remarks
	mastic asphalt.		instructions No bitumen was added. It was work- able and appeared to adhere well on the surface. The surface was covered with ¼-inch Bharatkup grit and lightly rolled. It was noticed a few days later that the grit did not hold well. Asphalt 84 pounds per 100 square feet.	surface had become rough and patchy within 6 months
17	Molasses treatment.	500—750	2½ maunds of quick lime was slaked with 5 maunds of water in a trough While this mixture was still hot, 7½ maunds of molasses was gradually poured in. Spramex, 1 maund, heated to 390 degrees Fahrenheit was added to this mixture and mixed quickly. This was then spread on the cleaned road surface to a thickness of 3/8-inch and blinded with a ½-inch layer of cinders, ¼-inch to ½-inch size. The cost worked out to Rs. 2/13/- per hundred square feet.	This was treated in December 1933 and in May 1936 it was found to be completely worn out. (Life 2½ years)
18	Shelspra carpet.	0—250	The slurry in the water-bound macadam was brought up to about ½ an inch of the top The grit for the first coat pre-coated with Shelspra B. S. was laid on the surface after 3 days After 5 weeks of laying the carpet the seal coat was given with 3 8 cubic feet of Shelspra B. S. per hundred square feet In the premix coat Shelspra-29 pounds and Gaya grit ½-inch to 5/8 inch—8 5 cubic feet per hundred square feet were used	Incomplete. The surface is standing well after two years.

No.	Name of experiments	Traffic intensity in tons	Particulars	Remarks
19	New methods of surface treatment.	250—500	The following experiments were tried in November 1938 in mile 24 of the Lucknow-Jhansi road :—	
			(1) ¾-inch carpet of Shelspra B S.—Cost Rs. 9/- per 100 square feet	Good upto date
			(2) 1 inch carpet of Shelspra B.S.—Cost Rs. 10/4/9 per 100 square feet.	Good upto date
			(3) 1 inch carpet of Shelspra B S. over priming coat of fuel oil and Spramex (70 per cent. and 30 per cent.) at 20 pounds per hundred square feet laid 24 hours before Cost Rs. 9/9/6 per 100 square feet.	Good upto date
			(4) Two coats of Shelspra at one month's interval : the first at 26·5 pounds per hundred square feet, and the second at 22 pounds per hundred square feet. Cost Rs. 3/7/- per 100 square feet.	Worn out and large number of patches have formed.
			(5) Two coats of Socony asphalt grade 105 applied at an interval of one month First coat was given using 40 pounds of paint per hundred square feet and in the second coat 27 pounds were consumed. Cost Rs. 4/5/8 per 100 square feet	Not much worn but a few patches have formed.

No.	Name of experiments	Traffic intensity in tons.	Particulars	Remarks
20	Digboi bitumen.	500—750	Digboi 60/70 and 90/100 grades were tried in comparison with Spramex 80/100 The grit used with Digboi paint was 1/8-inch to ¼-inch size, while with Spramex it was ¼-inch to ½-inch size. This was tried in April 1939 for painting and re-painting both	The experimental surfaces are standing well and not much difference is noticeable in the Digboi and Spramex surfaces.
21	Proctor's premix.	250—300	The road is thoroughly cleaned and brought to true formation and camber after repairing with Proctor's cold emulsion A priming coat is then applied consisting of deisel oil and Proctor's emulsion in the proportion of 1 to 3 at the rate of 18 5 pounds per hundred square feet, the emulsion containing 50 per cent Socony, grade 105. A light tack coat of 50/50 emulsion is applied with hair brushes just before laying the carpet 1½ inches thick carpet is laid, 4 cubic feet of ¼-inch to 5/8-inch grit being mixed with 28 pounds of Socony asphalt grade 105, 50 per cent emulsion ¼-inch and below size grit is also mixed with emulsion and spread over the carpet to fill up interstices. The carpet is then rolled with a 10-ton roller	Failure. Did not last well.
22	Shellspray B S. for re-paint compared to Spramex 180/200	500—750	This was used for re-painting at 17 pounds per hundred square feet, covered with 1/8 inch to 3/8 inch grit Mexphalte was also used with similar specifications, and no difference was noticeable so	Surface satisfactory in 1941

No.	Name of experiments	Traffic intensity in tons.	Particulars	Remarks
			far in the two surfaces treated in 1940. Cost of Shelspra re-painting—Rs 1/15 per hundred square feet against Rs. 2/3 for Spramex.	
23	Re-painting Bitumen miles with Tar No. 2.	over 1000	Re-painting with Tar and Mexphalte was tried side by side using equal quantities of bitumen and grit, and the Tar treatment was found economical. This was carried out in 1941 and the life of the two surfaces is still to be watched. Cost of re-painting with Tar is Rs. 2/14 per hundred square feet. Cost of painting with Mexphalte = Rs. 3/4 per 100 square feet.	Surface is satisfactory so far.

APPENDIX IV.

List of a few experimental lengths of concrete slabs.

Year	Thickness of *pavement* laid	Situation	Total *traffic* in tons	Present condition	Slab	Cost per *hundred* square feet	Remarks.
						Rs	
1926	9 inches-6 inches -9 inches	Mile 42 of Grand Trunk Road	750—1000	Good	16½ feet by 20½ feet	63/14/4	
		Mile 196 (1 furlong only) of Lucknow-Benares road (Benares side)	750—1000	Good	16 feet	. . .	Half the number of bays reinforced
1927	6 inches-4 inches -6 inches	Mile 423 of Grand Trunk Road	750—1000	Good	33 feet by 20½ feet	63/10/8	
1928	9 inches-6 inches -9 inches	Mile 413 of Grand Trunk Road	over 1000	Good	33 feet by 20½ feet	65/4/6	
1929	9 inches-6 inches -9 inches	Mile 40 of Lucknow-Jhansi Road	over 1000	Good	33 feet by 20½ feet	63/5/-	
	8 inches-6 inches -8 inches	Mile 54 of Lucknow-Jhansi Road	over 1000	Good	33 feet by 20½ feet	62/4/4	
	4½ inches	Machi-Bhawan bye-pass Road	over 1000	Good	20 feet by 20 feet	58/10/10	Only 844 square yards laid.

Year	Thickness of pavement laid	Situation	Total traffic in tons	Present condition	Slab	Cost per hundred square feet	Remarks.
						Rs.	
1930	7 inches-5 inches -7 inches	Mile 423 of Grand Trunk Road	750—1000	Good	33 feet by 16 feet	Not known	
	6 inches-4 inches -6 inches	Mile 424 of Grand Trunk Road	750—1000	Good	33 feet by 12 feet	Not known	
1931	6 inches-4 inches -6 inches	Mile 2 of Lucknow-Bareilly Road	500—750	Good	20 feet	Not known	
	4 inches	Mile 3 (240 feet only) Lucknow-Bareilly Road	500—750	Good	20 feet by 10 feet	Not known	
1932	6 inches-4 inches -6 inches and 5 inches-3 inches -5 inches	Mile 4 (590 feet only) Lucknow-Bareilly Road	250—500	Good	12 feet	Not known	
	4 inches-2 inches -4 inches	Mile 4 (308 feet only) Lucknow-Bareilly Road	250—500	Good	10 feet and 16 feet	Not known	
	4½ inches-3 inches -4½ inches	Mile 4 (490 feet only) Lucknow-Bareilly Road	250—500	Good	10 feet	Not known	
1935	5½ inches-3½ inches -5½ inches	Mile 860 of Grand Trunk Road	250—500	Good	33 feet by 12 feet	33/7/3	

Year	Thickness of pavement laid	Situation	Total traffic in tons	Present condition	Slab	Cost per hundred square feet	Remarks.
						Rs.	
	3 inches-2 inches-3 inches over 4 inches-3 inches-4 inches (brick ballast concrete)	Mile 56 (400 feet only) of Lucknow-Jhansi Road	250—500	Mile is in good condition.	33 feet by 12 feet	33/3/4	Plain
	3 inches-2 inches-3 inches	Mile 56 (200 feet only) of Lucknow-Jhansi Road	250—500	Good	33 feet by 12 feet	21/2/-	Reinforced.
936	6 inches-4 inches-6 inches	Mile 53 of Lucknow-Jhansi Road	over 1000	Good	33 feet by 12 feet	31/7/8	Continuous bay system.
937	3 inches-2 inches-3 inches	Mile 620 (3 furlongs) of Grand Trunk Road	over 1000	No difference between plain and reinforced; The small size grit has, however been crushed and some pot-holes have formed.	33 feet by 12 feet	21/4/11	Reinforced

Year	Thickness of pavement laid	Situation	Total traffic in tons	Present condition	Slab	Cost per hundred square feet	Remarks.
						Rs.	
	3 inches-2 inches -3 inches and 2 inches-2 inches -2 inches	Mile 630 of Grand Trunk Road	750—1000			24/6/9	Plain.
1938	3 inches-2 inches -3 inches	Mile 613 of Grand Trunk Road	500—750	Good	33 feet by 12 feet	28/9/6	Plain.
	$3\frac{1}{2}$ inches	Mile 37 of Lucknow-Jhansi Road	over 1000	Good	33 feet by 16 feet	36/-/10	Plain.
	4 inches-3 inches -4 inches	Mile 55 of Lucknow-Jhansi Road	250—500	Good	.	30/7/11	Plain.
1939	4 inches	Mile 123 of Lucknow Gorakhpur Road	over 1000	Good	50 feet by 20 feet	31/15/3	
	3 inches	Mile 72 of Lucknow-Jhansi Road	250—500	Good	33 feet by 12 feet	22/6/4	Plain.

Note.—In the case of slabs less than 3 inches thick, metal less than 1 inch size had to be used. It was found that under heavy load the metal was broken into pieces and the surface gradually developed into pot-holes. $1\frac{1}{2}$ to 2-inch metal is considered to be the minimum size which could be used for the coarse aggregate to take heavy loads.

APPENDIX IV *(continued)*

SHORT NOTES ON EXPERIMENTS ON CEMENT ROADS.

Roller crete.—The term Roller-crete has been given to cement concrete consolidated with a power roller.

This was tried on the Strand Road at Agra where the traffic intensity was 1757 tons, and due to the situation of a grain market and stone depots, this road carried very heavy unit loads.

Materials used—Sun-brand Gwalior cement with an initial setting time of 2 hours.

Fine aggregate	..	Chambal sand
Coarse aggregate	.	Bayana quartzite 1½ inches gauge and ¾ inch to ½ inch gauge mixed in equal quantities

The following mixes were tried :—

(1) 1 : 2 . 10

(2) 1 · 2 9

(3) 1 : 3 10

(4) 1 : 3 : 8

After laying the slab as usual, it was compressed with a 8-ton roller Tamping was later on done to bring the surface to proper camber using extra concrete to fill up depressions. The surface was very harsh and dry There was no creaming of mortar to the top. Stone chips mixed with cement 1 . 6 were rammed into all the interstices. After the usual curing for 21 days, 3 coats of silicate of soda were applied and the road was opened to traffic The thickness of the slab was 4 inches and the cost worked out to about Rs 22/4 per hundred square feet The work was done in November 1936.

Bays done with 1 3.10 mix began to show patches in January 1937 Bays with 1·3 8 stood fairly well till November 1939, but the slurry had worn out and the surface was uneven. Bays done with 1.2·10 showed signs of wear and began breaking soon after the road was opened to traffic.

Colloidal grouted cement concrete —This was tried on a road having a traffic of 1100 tons (motor and non-motor combined) The sub-grade was washed and brushed to promote adhesion The stone metal was spread and rolled with a 15-ton roller. Too much compacting was avoided The partially consolidated surface was allowed to dry out thoroughly. The mixture for the grout of cement, sand and water in equal parts was

made in a machine supplied by Messrs. J. C. Gammon. This grout was poured on to the consolidated surface and after 15 to 20 minutes the surface was tamped. Expansion joints were provided 50 feet apart. Two sections of slabs were tried, *viz.*,

(1) 3½-inch slab costing Rs. 32/10/3 per hundred square feet;

(2) 6 inches—4 inches—6 inches slab costing Rs. 36/1/9 per hundred square feet.

The grouting was completed in February 1939. Pot-holes appeared after a year, and the surface was found to be wearing very fast

Vibrated concrete.—The vibrator* used was of a pneumatic type and the complete outfit cost Rs 7,900/- It consists of an Air Compressor and a Vibrafit which is like ordinary tampers except that three pistons working in cylinders are fixed on it which cause vibrations in the tamper. The cost of vibrating concrete comes to Rs. -/14/10 per hundred square feet. Vibrated and hand-tamped lengths were laid side by side in 1939. So far, no difference is noticeable in the relative wear of the two surfaces.

Gunite Road Surfacing.—Gunite is cement mortar sprayed under pressure by a cement gun. This was tried with two mixes of mortars, *viz.*,

(1) 1 cement : 3½ sand ; and

(2) 1 cement : 4 sand.

on three types of surfaces, *viz.*,

(1) on cement concrete slab ;

(2) on water-bound stone metal ; and

(3) on water-bound kankar metal.

The average thickness of the coat was 1½ inches. In a small length, reinforcement was provided with B. R. C fabric 9 inches by 9 inches by 13 Gauge. The curing of the surface was done as usual for 21 days after which period it was allowed to dry and opened to traffic on the 28th day. The breaking started where Gunite had been laid over rolled stone macadam. Patches began to develop within a fortnight of the opening of road. The portion which appeared to stand best was the reinforced Gunite laid over kankar surface. Failure of Gunite had been mostly by scaling.

The average cost worked out to Rs. 31/5/6 per hundred square feet.

*Cf. Proceedings of the Indian Roads Congress, Volume VI, Appendix II, pages 55—56 and Appendix III, pages 125—132.

APPENDIX V.

(A) COMPARISON OF 4½" KANKAR WITH 3" SLAB OF CONCRETE FOR A 12 FEET WIDE MILE

R_K = Cost of renewal of a kankar mile

M_K = Annual maintenance cost of a kankar mile.

L_K = Life of kankar (in years).

R_C = Cost of concrete slab per mile.

M_C = Annual maintenance cost of a concrete mile.

L_C = Life of concrete.

and r_m = Rate of stone metal per 100 cft.

Annual cost of a kankar mile $= \frac{R_K}{L_K} + M_K$

Annual cost of a concrete mile $= \frac{R_C}{L_C} + M_C$

Equating, we get, $\frac{R_K}{L_K} = \frac{R_C}{L_C} + M_C - M_K$

Assuming $M_K - M_C$ = Rs. 150/-and L_C = 15 years, we get

$$R_K = L_K\left(\frac{R_C}{15} - 150\right) \quad \text{.. .. ..} \quad (1)$$

Analysis for a concrete mile is

Cement, 160 tons @ 35/- a ton	..	= Rs. 5,600
Sand, 8000 cft. @ 30/- per 100 cft.	..	= Rs. 2,400
Labour and Tools and Plant, Lump sum,	..	= Rs. 3,000
Stone,—16000 cft. @ r_m	..	$= 16000\frac{r_m}{100}$
Stone for subgrade, 8000 cft @ $(r_m - 5)$* % cft.		$= \frac{8000(r_m - 5)}{100}$

$\therefore R_C = 11000 + 160r_m + 80r_m - 400$

or $R_C = 10600 + 240r_m$ .. .. (2)

The different values of R_C as worked out from equation (2) above for the commonly prevailing rates of stone metal, have been tabulated below against the corresponding values of R_K from equation (1) above for lives of kankar road varying from 1 to 4 years.

* Difference in cost of metal suitable for concrete and for water bound assumed to be Rupees five only.

Life L_K	$r_m = 20$, $R_C = 15400$	$r_m = 25$, $R_C = 16600$	$r_m = 30$, $R_C = 17800$	$r_m = 35$, $R_C = 19000$	$r_m = 40$, $R_C = 20200$
	R_K	R_K	R_K	R_K	R_K
1	877	957	1037	1116	1196
2	1754	1914	2074	2232	2392
3	2631	2871	3111	3348	3588
4	3508	3828	4148	4464	4786

(B) COMPARISON OF 4½" KANKAR WITH PAINTING ON 4½" STONE METAL COAT—REPAINTING EVERY THREE YEARS; LIFE OF STONE COAT = 15 YEARS.

P_1 = Cost of initial painting, per mile.

P_2 = Cost of repainting, per mile

R_m = Cost of renewal of stone metal coat.

M_p = Annual maintenance cost of painting

Other symbols similar to those in (*a*) on the preceding page

$$\text{Annual cost of a painted mile} = \frac{R_m}{15} + \frac{P_1 - P_2}{15} + \frac{P_2}{3} + \frac{M_p}{1}$$

Equating to the cost for a kankar mile [as in (*a*) above] we get,

$$\frac{R_K}{L_K} + M_K = M_p + \frac{R_m + P_1 - P_2}{15} + \frac{P_2}{3}$$

$$\text{or} \quad \frac{R_K}{L_K} = \frac{1}{15}(R_m + P_1 - P_2) + \frac{P_2}{3} + (M_p - M_K)$$

Assuming $M_K - M_p$ = Rs. 125/-,

P_1 = Rs. 3080/- @ -/7/- per square yard,

P_2 = Rs. 1760/- @ -/4/- per square yard,

$$\text{We get } \frac{R_K}{L_K} = \frac{R_m}{15} + \frac{1320}{15} + \frac{1760}{3} - 125$$

$$= \frac{R_m}{15} + 88 + 586 - 125$$

$$= \frac{R_m}{15} + 549$$

$$\therefore \quad R_K = L_K\left(\frac{R_m}{15} + 549\right) \quad \ldots \quad (3)$$

And $R_m^{*} = (r_m + 3.5)\, 240^{\phi} + 500^{\theta}$ . .. . (4)

The different values of R_m as worked out from equation (4) above for the commonly prevailing rates of stone metal have been tabulated below against corresponding values of R_K from equation (3) above for lives of kankar road varying from 1 to 4 years

Life	$r_m = 20$ $R_m = 6140$	$r_m = 25$ $R_m = 7340$	$r_m = 30$ $R_m = 8540$	$r_m = 35$ $R_m = 9740$
	R_K	R_K	R_K	R_K
1	958	1032	1119	1198
2	1916	2064	2238	2396
3	2874	3096	3357	3594
4	3812	4128	4476	4792

These figures have been plotted in the two following graphs from which the economical life of kankar as compared with painting and 3-inch concrete for varying rates of stone metal can be easily read off. The rates of kankar corresponding to costs of renewal of kankar miles have also been plotted on these graphs

Example —Rate of Kankar = Rs 10/- per hundred cft.

Consolidation of Kankar = Rs 2/- per hundred cft.

Total cost = Rs 12/- per hundred cft.

Rate of stone = Rs. 25/- per hundred cft

From Graph 1, the annual cost of a kankar mile and a 3-inch cement concrete mile would be the same if life of kankar is 3 years.

If the rate of stone is Rs 40/- per hundred cubic feet, the equivalent life of a kankar mile would be 2 4 years only

Similarly, from Graph 2, we get the equivalent life of kankar as compared to a painted surface as three years when stone is Rs. 20/- and 2 4 years when stone is Rs. 35/- per hundred cubic feet.

As the difference between the cost of metal suitable for concrete and water bound is generally Rs. 5/- per hundred cubic feet, it is clear from the above that the annual costs of 3" concrete and painting are the same when the life of painting is 3 years and of concrete 15 years for which these graphs are drawn.

*Rate of consolidation per 100 cft = Rs 3.5

θ Cost of blinding per mile = Rs. 500/-

$\phi = \frac{4\frac{1}{2}}{12} \times 12 \times 5280 \times \frac{1}{100} = 238$

TABLE I

Graph showing comparison of $4\frac{1}{2}''$ kankar with $3''$ slab of cement concrete for a 12 feet wide mile

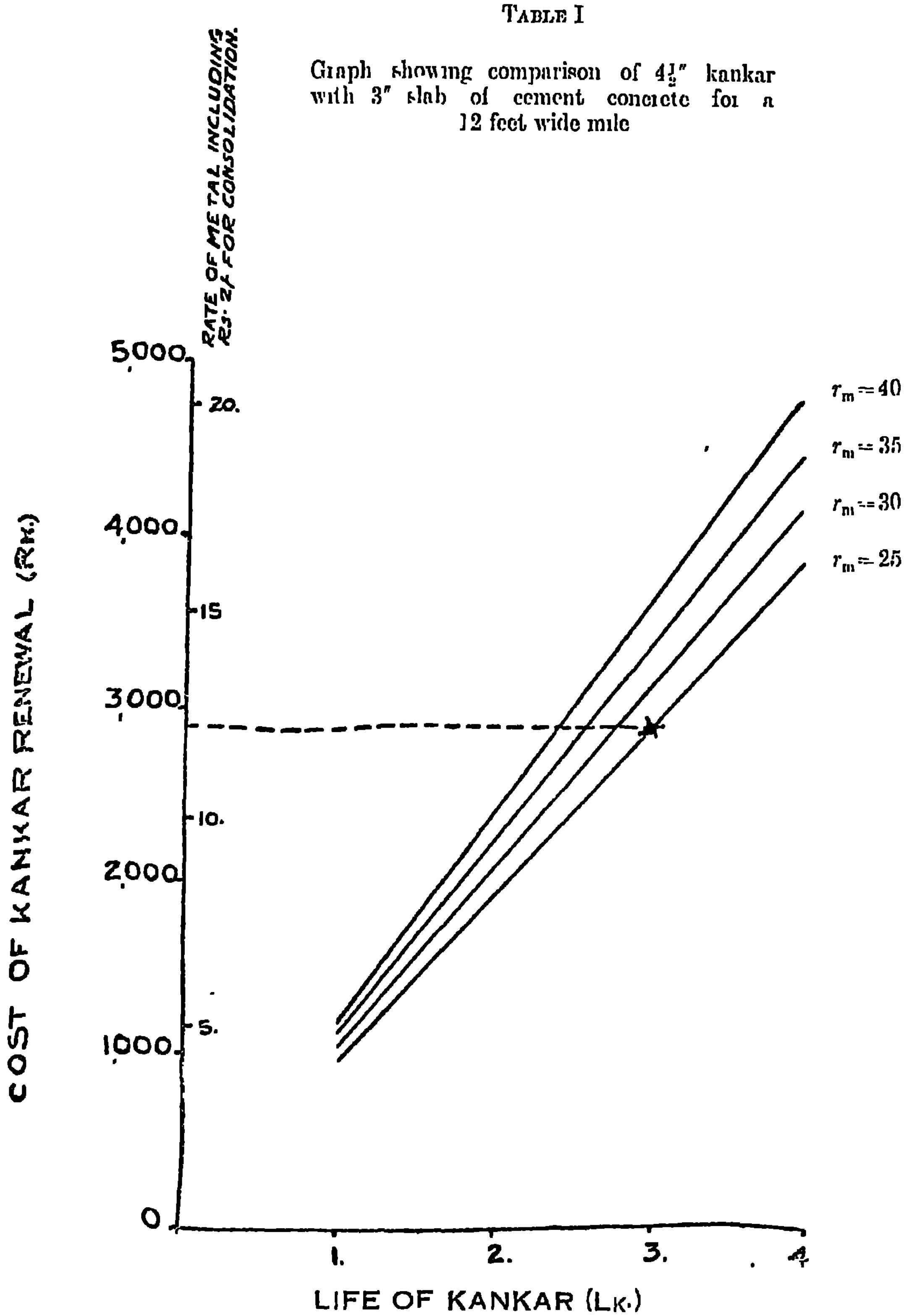
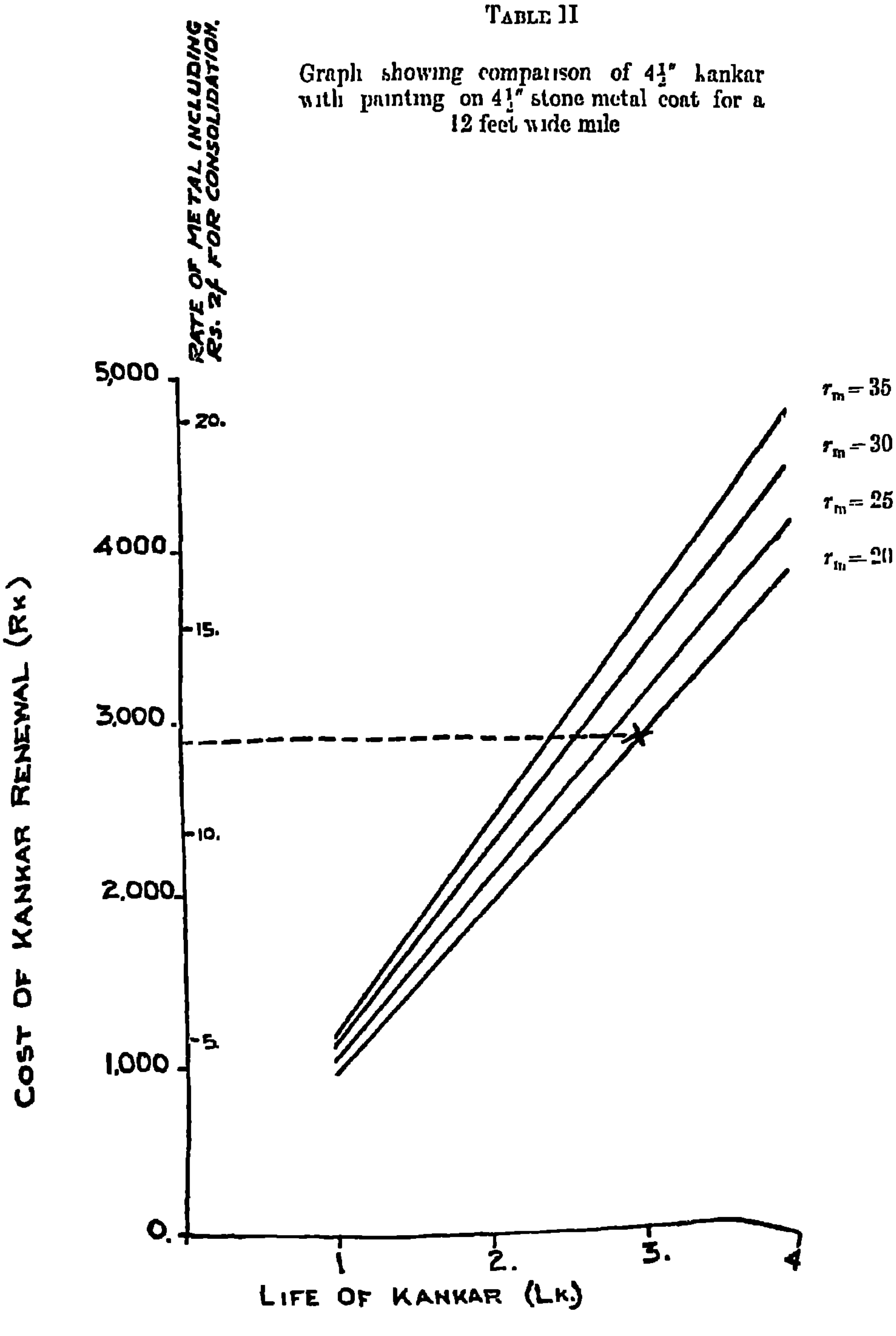


TABLE II

Graph showing comparison of $4\frac{1}{2}''$ kankar with painting on $4\frac{1}{2}''$ stone metal coat for a 12 feet wide mile



APPENDIX VI.

CENSUS OF TRAFFIC ON PAINTED MILES.

Serial No.	Name of road		Traffic Lanes.	Traffic per traffic lane (tons.)				Actual Life (years)	Remarks.
				Carts		Motor	Total		
				Iron tyred	Total				
1	Bareilly-Almora Road....	Mile 6	1	228	880	400	1280	5	
2	Bareilly-Almora Road. ..	Mile 29	1	236	534	700	1234	5	12 feet wide miles are considered as unit width, and 16 feet as 1½ units and traffic figures have been reduced accordingly.
3	Bombay-Delhi Road	Mile 751	1½	138	303	637	940	5	
4	Meerut-Bareilly Road ..	Mile 2	1½	198	621	285	906	5	
5	Grand Trunk Road	Mile 876	1½	154	233	613	846	5	
6	Meerut-Bareilly Road .	Mile 126	1	156	415	300	715	5	
7	Lucknow-Bareilly Road	Mile 149	1	181	461	203	664	4·5	
8	Agra-Aligarh Road	Mile 33	1½	84	174	111	285	4·3	
9	Grand Trunk Road	Mile 801	1½	507	793	233	1026	4·0	
10	Bombay-Delhi Road......	Mile 752	1½	86	191	714	905	4	
11	Agra-Aligarh Road	Mile 6	1½	182	286	417	703	4	
12	Bareilly-Etawah Road ..	Mile 136	1½	692	922	33	955	3·5	
13	Dehra Dhaki Road ...	Mile 1	1½	166	212	547	759	3·5	
14	Grand Trunk Road ..	Mile 671	1	201	496	366	862	3·5	
15	Bareilly-Almora Road....	Mile 3	1	179	856	500	1356	3·3	
16	Lucknow-Gorakhpur Road	Mile 82	1½	616	810	187	997	3·3	
17	Bareilly-Muttra Road	Mile 1	1½	154	677	90	767	3·3	
18	Bareilly-Muttra Road . .	Mile 1	1½	66	465	136	601	3·3	

Serial No	Name of road		Traffic Lanes	Traffic per traffic lane (tons)				Actual Life (years)	Remarks
				Carts		Motor	Total		
				Iron tyred	Total				
19	Lucknow-Gorakhpur Road	Mile 17	1	275	575	548	1123	3	
20	Delhi-Rajpur-Mussoorie Road	Mile 150	1½	64	82	978	1060	3	
21	Agra-Aligarh Road	Mile 3	1½	410	1013	896	1909	2 7	
22	Delhi-Rajpur-Mussoorie Road	Mile 40	1½	316	560	284	844	3	
23	Sitapur City Branch	Mile 1	1½	360	437	267	704	3	
24	Lucknow-Bareilly Road	Mile 4	1	139	323	164	487	3	
25	Saharanpur-Dehra Dun Road	Mile 1	1	116	200	763	963	2 6	
26	Bareilly-Almora Road	Mile 25	1	238	684	580	1264	2 5	
27	Delhi-Rajpur-Mussoorie Road	Mile 105	1	146	232	569	801	4	
28	Delhi-Rajpur-Mussoorie Road	Mile 104	1	56	86	450	536	3	
29	Delhi-Rajpur-Mussoorie Road	Mile 41	1½	58	177	284	461	3	
30	Meerut-Bareilly Road	Mile 128	1½	150	402	210	612	2·2	
31	Bareilly-Etawah Road	Mile 134	1	396	659	54	713	2	
32	Grand Trunk Road	Mile 626	1½	98	239	237	476	2	
33	Delhi-Rajpur-Mussoorie Road	Mile 148	1½		109	1823	2232	1·5	

DISCUSSION.

Mr. N. V. Modak (Chairman) called upon Mr. S. N. Chakravarti to introduce his paper. Then the above paper was taken as read. Mr. Mahabir Prasad introduced the paper on behalf of Mr. S. N. Chakravarti.

J. T. Mehta (Bhavnagar) :—In the United Provinces the Engineers are agreed that when the traffic is more than a painted surface will stand, Cement Concrete is the only economical form of surface to adopt. I am inclined to agree with this view point for the following reason. Even if we take for granted that one inch asphalt macadam carpet, as is being told by advocates of this form of surface, has an economic life of 12 years, the annual road cost of 4 inches cement concrete will be equal to that of 1 inch asphalt macadam if the former be taken to have an economic life of only 13 years, taking into consideration the interest on the capital outlay at the present rate of $2\frac{1}{2}$ per cent.

The detailed calculations are given below :—

For one mile of road 18 ft. wide the cost of
(a) asphalt macadam @ Rs. 13 per 100 Sq. ft. would be .. .. Rs. 12,400/-
(b) 4 in Cement Concrete without dowels @ Rs. 33 per 100 Sq. ft. would be . Rs. 31,400/-

A seal coat on (a) every fourth year with 10 per cent of surface for reinstatement would cost Rs. 6,500/-

Ordinary maintenance :

for Cement Concrete like filling joints, washing, making berms etc. per year would cost Rs. 250/-
Do for asphalt road like ordinary patrol maintenance, brushing, making berms etc. per year Rs. . .. 200/-
At the end of the economic life of concrete road, it will have a salvage value equal at least to the cost of a 3 in. coat of W. B. macadam, which is taken as Rs. .. 5,000/-
Then,

Annual cost of road surface =

$$\begin{pmatrix}\text{Annual return}\\ \text{on value}\end{pmatrix} + \begin{pmatrix}\text{Annual depre-}\\ \text{ciation}\end{pmatrix} + \begin{pmatrix}\text{Annual cost of}\\ \text{periodic maintenance}\end{pmatrix} + \begin{pmatrix}\text{Annual cost of routine}\\ \text{maintenance.}\end{pmatrix}$$

$$= V_n r + \frac{(V_n - V_S)r}{(1+r)^{n-1}} + \frac{M_p r}{(1+r)^{n'-1}} + M_A$$

where V_n = Value new.
r = rate of interest (say $2\frac{1}{2}\%$).
V_S = Salvage value.
n = economic life of surface in years.
M_A = Annual maintenance.
M_p = Periodic treatments.
n' = Life of periodic treatments.

For cement concrete this will be :—

$$31400 \times 0.025 + \frac{(31400-5000)\ 2.5}{3.5^{12}} + 250$$

= Rs. 2517 annual cost.

For 1" asphalt macadam this will be :—

$$12400 \times 2\tfrac{1}{2}\% + \frac{12400 \times 2\tfrac{1}{2}}{3.5^{11}} + \frac{6500 \times 2\tfrac{1}{2}}{3.5^{3}} + 200$$

= Rs. 2516 annual cost.

It has been stated by the Author that in order to minimize blow-ups in thin slabs, these are bonded on to the subgrade and an expansion joint $\frac{3}{8}$ in. thick is provided at the end of each slab The bonding will increase the coefficient of sliding resistance between the slab and the subgrade beneath it, thereby producing tensile stresses in the concrete when the slab contracts I would like to know whether dummy contraction joints are provided to shorten the length of the slab and reduce these stresses, as also how many transverse cracks have appeared in one slab. If these thin slabs are bonded, what practice is being followed for 4 in. thick slabs? Are they insulated with paper or sand? Are they provided with expansion and contraction joints or is simply alternate bay method relied upon? I would like to know the detailed specifications for 4 in. slabs.

Finally I think that the use of thin concrete roads is the only solution for heavy mixed traffic, and it is time that the Engineers of the Concrete Association of India devote their attention to the evolution of design for thin slabs and specifications for them on scientific lines.

Rai Sahib S. K. Ghose (Bihar):—

The United Provinces were very fortunate indeed in getting a loan of rupees 144 lakhs from the Government of India for road surfacing work as early as 1924, and also in spending the whole amount in five years only in improving 596 miles of road. Other provinces were evidently not as lucky, as a result of which U P. has definitely stolen a march in road improvement. Her engineers have now actually proved that 3 inch cement concrete bonded slabs of uniform thickness (without thickened edge, steel reinforcements, or insulation paper, concrete machine-mixed but hand-tamped) can be successfully done for Rs. 22 per hundred square feet, and can carry more than 500 tons of cart traffic (on a 12 ft. width of road) for at least 15 years Will other provinces please copy?

The Queensland Main Roads Commission making similar experimental work on 3 inch concrete road slabs, 8 ft wide on Brisbane Valley Highway, in 1940, used elaborate tongue joints along the centre line (for a 16 ft. roadway) and reinforcements at the centre, edges and also radial corner bars Even then, there were cracks at the corners. The foundations consisted of old, hard, gravel road. The importance of bonding the cement concrete road on to an old water-bound macadam surface of at least 6 inches thickness is apparent.

The average costs of cement concrete slabs as noted in lines 9 and 25 of page 11, and line 14 on page 13, are found to vary from Rs. 22 per

hundred square feet to Rs. 25 per 100 cubic feet. There appears to be an error, and it would have been helpful if an analysis of the average costs for the different items of work were appended.

The curing done with a 6 inch layer of earth would appear to be unusually conservative, and would require a lot of earth. Could we not use a thin layer of wet sand say 1½ inch thick with better results?

The traffic statistics are quite useful for giving a correct idea of present-day traffic, but it is a moot point whether we should not provide for expected traffic likely to develop 5 or 10 years later. It was not, of course, possible to predict the sudden development in road traffic due to the present war. But we should be able to assess future tonnage of road transport from statistics of other similar areas and it would be better to err on the higher side, so that we may not have to change from kanker to sealed water-bound within say 2 to 3 years.

It is heartening to learn that Digboi asphalt has stood the tests and is just as good as Spramex. We must try to use Indian materials more and more, if we want to reduce the India's Road Bill.

Mr. Chakravarti deserves our heartiest congratulation for the very useful notes he has collected and presented for the benefit of road engineers in other provinces. Doubtless, his presence in the P. W. D. Secretariat made it easier for him to collect all the information and it is suggested that the Indian Roads Congress might request other provinces for similar experimental data, which would be most valuable in formulating All-India Road construction policy and technique.

Rai Bahadur M. A. Rangaswami (Bihar) :—

It is an excellent paper, giving the results of tests and experiments carried over a period from 1926-1940, on the merits of different types of treated road surface in U. P. So far as U. P. is concerned, the conclusions arrived at are given in page 10 of the paper. It is said that kunkar surface or brick metalled surface will not take more than 500 tons of mixed traffic per day. Secondly, if the intensity of cart traffic is more than 500 tons per day painted surface will not stand the traffic. Thirdly, cement concrete surfacing is the only remedy for traffic of above 500 tons (Bullock cart traffic) per day on 12 ft. width of road.

Conditions in North Bihar are very much the same, as some of the Districts in U. P. bordering Ganges river and conclusions arrived at in U. P. can be easily adopted in North Bihar and possibly in deltaic areas.

Pages 237-238 of I. R. C. Proceedings, Volume III, 1937, give interesting results of different types of treatment of road surfaces, under different intensities of traffic. On the Grand Trunk Road, between Bulandshahar and Ghaziabad the kunkar surface lasted for only two years and from reports of experiments carried on this road, vide page 247 of I.R.C. Proceedings, Delhi, January, 1941, it is noticed that the section of Ghaziabad Bulandshahar road was improved by adopting cement concrete, after doing 5 miles reconstruction with Delhi stone metal surface. The cement concrete was done 1935-1937. The intensity of traffic was 594

tons in 1934 and 1268 tons in 1939. Obviously, for such intensities of traffic, cement concrete is the only remedy.

Sir Kenneth Mitchell in his excellent paper, vide pages 49—65 of I.R.C Proceedings, Vol. VII, Part I, had suggested the adoption of cement concrete track-ways for bullock cart traffic. I had constructed cement concrete-creteways in 1936, in 30 ft feet strips, on an important road and all sorts of traffic passed over it, and it is in excellent condition—no repairs ever having been done to it In this connexion, I would also refer to Stuart Chandler's note on Road Development in Southern Rhodesia.

It is understood that the U. P. Government are going to improve the existing road surface to a length of 101 miles at an estimated cost of 17'12 lakhs obviously using cement concrete for the whole roadway.

Might it not be possible to segregate bullock cart traffic, construct cement concrete creteways, on the lines suggested by Sir Kenneth Mitchell, and keep the other surface painted for fast moving vehicular traffic? That would probably bring down the estimate of 17'22 lakhs to about 12 lakhs.

Mr. Muriell, in his paper No. C. 41, has pointedly drawn the attention of Engineers and the I R.C. to the need for minimising wastage under Technical and Administrative side and Preventable wastage, in the shape of improvement of bullock-cart wheel. Mr. Vesugar has, in his paper No. J-1943, drawn the attention of the Engineers of this Congress to the need for a survey of the road conditions and the users of the road, particularly the extent and period of bullock cart traffic.

The type of surface, to be adopted certainly, depends on the intensity and volume of traffic, and if any wastage is to be prevented the type of road surface to be adopted, depending on the intensity and volume of traffic, should be specified and it is time, the I.R.C. issues general directions towards that object.

Mr. Chakravarty's conclusions, after years of experiments in U. P., should pave the way for issue of general instructions by the Indian Roads Congress.

Mr. C.J. Fielder (Shalimar Tar).—Members will be indebted to Mr Chakravarti for having so clearly summarised the various methods of Road surface treatment tried and adopted in the U. P. I would like to comment on one or two aspects of the bituminous treatment described in the paper.

Premix Macadam is reported to have been found a costly failure. The binder employed was, I note, a fluxed natural asphalt. Experience elsewhere in India has shown with other types of binder tar or bitumen that this method of treatment can give sound and economical results which justify its adoption under heavy traffic load. It would seem, therefore, that further trials with premix macadam would be worth while.

Grouting also has been found successful, especially in Bengal. The specification given by the author reveals that a seal coat was applied before allowing traffic on the grout. It has been my experience that it is desirable to allow traffic on for a few weeks before applying the seal coat as any weak points will show up during the compaction which takes place under traffic and can be corrected at the time of laying the seal. A further improvement which more than repays the extra labour involved is to spread the stone chips *premixed*, instead of dry, over the grout. No extra binder need be employed for this and the resulting improvement in the evenness of profile and camber is most marked.

For *Surface Painting*, it appears that no grade thicker than road tar No. 2 has been employed. The use of the more viscous grades of road tar Nos. 3 & 3A for second and subsequent coats is now fairly general standard practice and I am confident that they will prove more effective and economical under the climatic conditions of the U. P. Actually, at the request of the authorities, no grades of road tar thinner than No. 3 are at present being manufactured and results with the thick grades on metalled and kankar roads in the U. P. will be of much interest.

On page 9, para. 2, the author states that for repainting, it is the consensus of opinion that the minimum quantity of binder required to cover the surface should be used. This, however, is not quite the correct way to approach the problem, as the minimum quantity of binder to cover a given surface can be varied between limits depending on the temperature of the binder and to some extent the temperature of the surface.

The real factor which should determine the quantity of binder to be spread is the size of chippings to be employed. The larger the size grading 1/4 in., 1/2 in., or 3/4 in the greater the quantity of binder required - say 16 lbs., 24 lbs., or 32 lbs. per 100 sq. ft. The binder should then be heated to the lowest temperature at which the desired spread can be attained.

It is particularly interesting to note that the author has attempted to classify the various types of stone metal chippings available in his province in respect of their relative affinity for binders. The results are shown in Appendix II of the paper. I have given affinity tests a certain amount of attention and a word of warning is necessary as regards the use of such tests in respect of their application to road tars. As is well known, road tars set by virtue of the evaporation of lower boiling oils rather than by mere cooling as in the case of bitumen. The former process takes time especially in the case of such a thin tar as No. 1 and samples of chippings coated with tar should be exposed for at least 48 hours, preferably longer, when they are hydrophilic, before submitting them to an affinity test. The author does not give complete details of his test but presumably he has coated his chippings and shaken them with water without permiting sufficient time to elapse for the tar to set up, which gives the water a better chance to strip off the tar, while it is still comparatively fluid. Testing under such conditions presupposes that the road surface is to receive the full blast of monsoon rains within an hour or so of the application of the road tar.

Members may be interested to hear that, as a result of the exigencies of war time conditions, we have found it possible to carry out surface treatment with road tar during monsoon rains with every success, by the simple expedient of first adding lime to the metal. This has the effect of absorbing the water on the damp metal surface and the lime then acts as a filler and bestows a quick set upon the road tar. This has been applied with excellent results both for premix work on aerodrome runways and on roads.

While on this subject, I am prompted to suggest that the Congress might, through their Technical Sub-committee, assist Road Engineers by standardising the tests to be applied to stone metal so that they may be able to select from a variety of sources of stone metal those most suitable for water-bound macadam construction and for bituminous treatment These tests would include physical tests for crushing strength, attrition test as well as a test for adhesion. Such tests would be at first somewhat tentative, but if Engineers would record their results in the field with laboratory test results, correlation should lead to the adoption of testing procedure which would form a valuable guide in the selection of the best stone metal for road construction

PAPER No C-41

RAISING THE ROAD RUPEE RATIO WITH A SPECIAL REFERENCE TO THE STEEL TYRE.

BY

W. L. MURRELL, O.B.E., B C.E.(MELB.), A.M.INST.C.E., I.S.E.,
Superintending Engineer, North Bihar Circle, Muzaffarpur.

It is believed that our President gave us the expression "Road:Rupee Ratio". And most of us see in it our three R-s. Indeed, "Raise the Road: Rupee Ratio !" is the slogan of every one of us-otherwise we would not have become members of the Indian Roads Congress.

One Expression for the Ratio is

$$R = \frac{M - W}{M}$$

where M = The total expenditure on vehicles and on road work.

W = That portion of M which is spent inefficiently, that is to say, money wasted.

Obviously, the best way to raise the ratio is to decrease W, and the object of this Paper is to invite discussion on and, if possible, come to some decisions on methods of reducing waste.

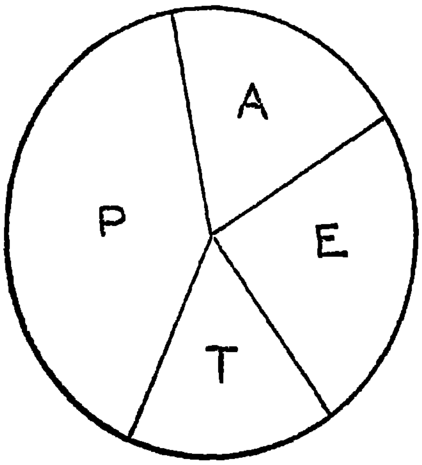
So far as the motor vehicles are concerned, many owners will say that their present office and establishment expenses are much too high and wasteful in comparison with the number of miles run, and that a greatly increased milage of good low-cost roads would prevent this wastage.

The owners of both the motor and the animal-drawn vehicles may say that the best way to prevent waste in running and vehicle maintenance costs is for the road engineer to provide better roads for their vehicles to run upon.

In reply, we road engineers might point to a little excess weight in the construction of the cart, or to many draught animals being out-of-condition, and thus not being able to give reasonable yoke pressure per unit weight of animal. Or we, in times of peace, might point to obsolete and wasteful motor vehicles. But we must surely admit that by far the most effective means of reducing transport costs is to have something less unreasonable in the way of roads.

Therefore, we proceed to the consideration of wastage in road construction and maintenance.

If the wastage were represented quantitatively by the area of a circle, a suggestion for the subdivision of the circle is shown below -



A—Administrative wastage

E—Executive wastage

T—Technique wastage

P—Undue wear and tear, or preventable wastage.

W—Area of circle, $= A+E+T+P$.

It is possible and even probable that the reader will disagree substantially with the above subdivision. In such event it is suggested that, before reading any further, he make his own wastage circle and subdivision and then continuing to read, refer to his own arrangement of the respective "wastage sectors".

Sector A.—Administrative wastage.

On pages 6 and 7 (j) of the printed proceedings of our Sixth Meeting, a roseate but true account was given of road administration in the federated provinces of Australia; but the account did not mention the "skeleton" in the Australian "cupboard".

When the Australian Federal Constitution was being framed, roads were left strictly as a matter for the provinces Federation took place in 1900 but, for years thereafter road matters continued to be muddled Systems were tried and discarded and all the time, the country developed at a far greater speed than its road system.

At last, the ever-growing national spirit demanded that something must be done, and the first wholetime provincial roads board or commission was formed in 1913, the other provinces followed suit later when they saw how well the system was working in the neighbouring province.

In other words, many precious years were lost before the new young nation began to receive the benefits of an adequate road system.

Had the Federal Constitution been on the American model, with roads as a Central subject as well as a States subject, all that waste of time in achieving efficient organisation and an adequate road system would have been avoided.

Had the Indian Roads Congress Resolution* of December 1939 asking for the Committee of Enquiry been granted, much vital information would have been obtained which would have proved invaluable to help the framers of India's future Constitution.

So now, to prevent a future administrative situation such as occurred in Australia and is occurring in India to-day, it is suggested that our Roads Congress set up a standing " Constitution Suggestion Committee" whose sole object would be to collect, and record opinions on, suggestions for consideration by those who will frame the future Indian Constitution. Not at any stage would there be publicity or anything that would make it appear that the Roads Congress was going outside its own sphere, and meddling in politics.

Like the proposal made in the last war that our airmen might be given parachutes, this may seem a crazy suggestion, but there is great danger of the framing of the future Constitution being left to politicians who will naturally follow existing patterns The politicians need sound practical advice as regards road administration. Who better could collect suggestions, than the Indian Roads Congress ?

Indeed, who else is to make any suggestions at all on this matter ?

Sector E.—Executive Wastage.

Here, considerations commence with the training of the Road Engineer in India and, in this respect, our Roads Congress has made a start by inviting competitive essays on this subject.

But, if India is to reap the benefits of this competition, there must be some agency by which some of the improved methods suggested by the competitors, can be collected, given the commendation of our Roads Congress, and sent on to those who can give effect to the suggestions. The matter has also been touched upon on page 8 (j) of the printed Bombay† proceedings.

It is, therefore, suggested that our Roads Congress might set up a standing "Provincial Suggestions Committee" to consider suggestions and to recommend to the Council what matters might be addressed to educational institutions, local governments, and others.

Thus also we might deal with wastage arising from the conditions of employment of the executive, from Overseers upto Executive and District Engineers.

Much waste arises from the system of rotational transfers of subordinate staff between buildings, irrigation, and roads jurisdictions, by which untrained and sometimes uninterested subordinates do road work that really requires special knowledge and keenness.

Interest and keenness can be increased even among the ordinary staff

* Proceedings of the Indian Roads Congress, Volume VI, Discussion on Paper J-39, page 34 (j)

†Proceedings of Indian Roads Congress, Volume VI.

by the system of inviting competitive essays Rs 50/- spent in a road Circle might easily save Rs 5,000/- annually. This also might be suggested to all concerned.

Those provinces which have not got a Special Officer in charge of roads need at least the equivalent of the provincial Forest Research Officer to advise on road work, co-ordinate research, and to modernise provincial roads technique.

As regards the conditions under which all except the Madras District Engineers work, all will agree that, if waste is to be prevented, a few freedoms, including that from fear, must be ensured to the District Engineers by provincialising their service, either under Government or by having a local self-government service It would be for the Roads Congress Council when opportunity presented itself, to consider and send on the recommendation of the Provincial Suggestions Committee in this matter also Or, at the very least, this matter should be left in the "glory-box" of the Constitution Suggestion Committee

In order to prevent the Roads Congress from being considered as a sort of road engineers' professional union, any activity of our proposed committee would be confined strictly to questions of general principle only Dealing with individual cases would be barred absolutely

Before passing on to the remaining "wastage sectors" T and P of the Circle W, it may be noted that the sectors A and E together form a substantial part of the total area In other words, if the Indian Roads Congress is content to confine itself to strictly technical considerations in future, it will be neglecting much of the field in which wastage can be prevented, and the future road. rupee ratio will then suffer severely by our continued complacency, not to say our lack of sense of civic responsibility.

Sector T.—Waste arising from inefficiency in the technique of road engineering and maintenance.

Undoubtedly, two great causes of waste are the unsuitability of many surfaces for the kind of traffic they have to carry, and inefficiency in maintaining such surfaces Much of this is unavoidable on the score of finances, so we are here concerned with the waste that can be prevented by change of technique. The prevention of waste by providing a higher type out of loan money would come under sector A—Administrative

Most of us have seen cases where brick metal or kunker roads have been constructed when, owing to the steel-tyre traffic, either a lower or a higher type of surface should have been provided

We have seen a premix fail because the aggregate was not tough enough, or a suface dressing spoiled because the chips were too tough or too large for the quantity of binder allowed, — And so on.

But, whether our past failures were due to ignorance or to the use of out-of-date methods, nobody can say that the Indian Roads Congress is not doing its best about this Sector T. Our meetings and the printed records of them are sufficient proof of that! The necessity for more papers describing failures is now the more evident.

Perhaps our Provincial Suggestions Committee could devise ways and means of getting the respective Governments to increase the number of their delegates to the Roads Congress.

The members of the Council and of the various Sub-Committees, not to mention the writers of papers, many of them 'hardy annuals', take up pretty well all the Government-delegated places, and there is insufficient "new blood" in the annual meetings.

So far as the general improvement in technique is concerned, it is essential that many more young men should be coming to the annual meetings, and comparing notes with engineers from the neighbouring provinces

There is another direction in which we seem to be slipping-up in this matter of preventing technique wastage

High in the list of the declared objects in our Memorandum of Association occurs the item—"to promote the use of standard specifications and to propose specifications".

The reason for this will be clear when it is remembered that the best way to get work done well, and so prevent wastage, is to have a contract based on a good specification.

There are many items of road-work which should be represented by good up-to-date specifications in the hands of those subordinate to the Executive and District Engineers, and attached to the contractor's copy of the contract, especially in the more important road works But such specifications and copies are all too few and, in many cases, there is really no definite specification at all.

Here, then, cannot our Roads Congress step into the breach by publishing specifications ?

A few members have had a try to produce specifications for adoption by the Roads Congress, but the difficulty is that many of us fail to realise that half-a-loaf is better than no bread, and so what is put up in the way of a specification is picked to pieces and then virtually shelved. It does not receive the backing of the Roads Congress even in a modified form, or as a Roads Congress publication disclaiming responsibility and inviting suggestions for revision.

Sector P.—Undue wear and tear, or preventable wastage on the roads themselves.

As regards motor vehicles, we now know that the high speed and excessive unsprung weight of motor vehicles play havoc with all forms of surface lower than surface-dressed macadam.

Surely, it would be reasonable to take some action through our Provincial Suggestions Committee to prevent at least public and private carriers and all six-wheeled and other vehicles with excessive unsprung weight, from running at excessive speeds ? In this we would secure the co-operation of many of the vehicle-owners themselves.

Animal-drawn vehicles other than the bullock cart are, generally speaking, light in weight, and the wear and tear due to them can scarcely be said to be undue.

The number of pneumatic or reasonably well-conditioned broad wooden-tyred bullock carts being insignificant in comparison with the number of steel-tyred bullock carts, it is to the last-named that the writer again attributes the greater part of the wastage sector P.

It might serve some purpose to estimate roughly what this preventable wastage is

According to "Indian Roads" for June 1938, the roads in All-India total about 2,11,000 miles, including all kinds of motorable roads By substituting for the steel-tyre with a broad tyre of the hardness and toughness of hardwood, we might save, say Rs. 400/- a mile in some cases, and Rs 50/- a mile in others, per annum If the average saving were only Rs 100/- per mile, the All-India saving by adopting a compromise tyre would be something like Rs Two crores annually!

This sum should, therefore, be considered as annual waste if it can be shown that the compromise tyre is ultimately practicable on an almost universal scale The remainder of this Paper is a further attempt to show that a compromise tyre will be attainable more or less universally

The following are the obviously essential qualifications for any new feature in the bullock-cart wheel —

(i) The feature must result in the minimum possible change in design of the present wheel

(ii) The new feature must be capable of fabrication by the existing village blacksmiths and wheel-wrights, and at reasonable expense.

(iii) The new tyre must be reasonably resistant to wear

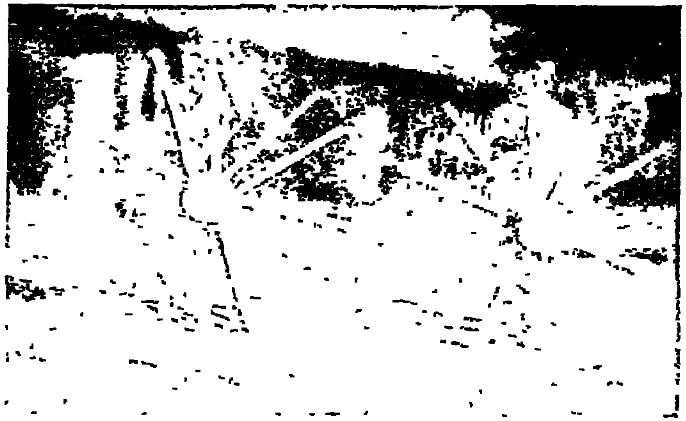
(iv) Repairs must be inexpensive, and within the scope of the existing village wheel-wrights

(v) It would be good if the new tyre could be fitted to existing bullock-cart wheels

As regards its hub and spokes, the Indian bullock cart wheel is divided into two main types as shown in Photograph I

For want of a better name, I have called each of these assemblies a "spider"

The spider on the left consists of six arms, generally curved, driven through the hub. The widest and thinnest pair are driven from opposite sides first. The three pairs of arms go right through the hub, avoiding the axle and interpenetrating among themselves This work no less than the fitting and wedging of the six sections of wood felloe and their connecting wooden dowels in the wheel of the ordinary bullock cart must incidentally, arouse our admiration for the very skilful work of the ordinary Indian village wheel-wright.

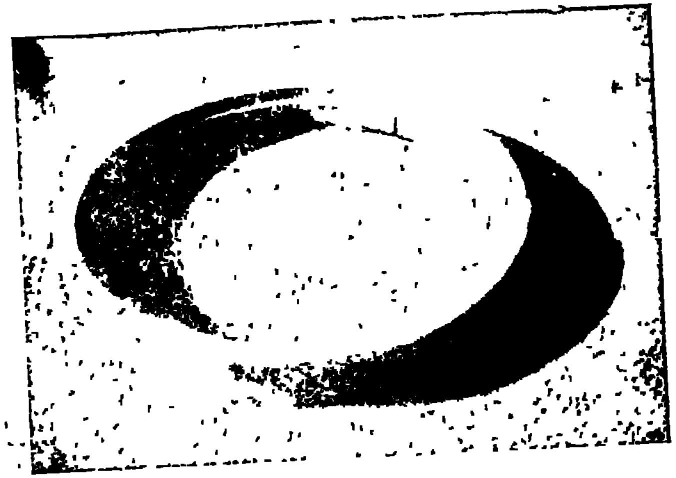


1
A-type and S-type "Spiders".

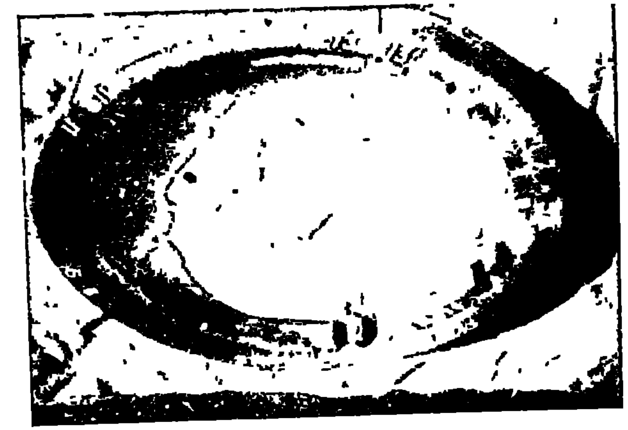
3
Flange rings.

2
T-shaped broad wood tyre sections, stalk uppermost.

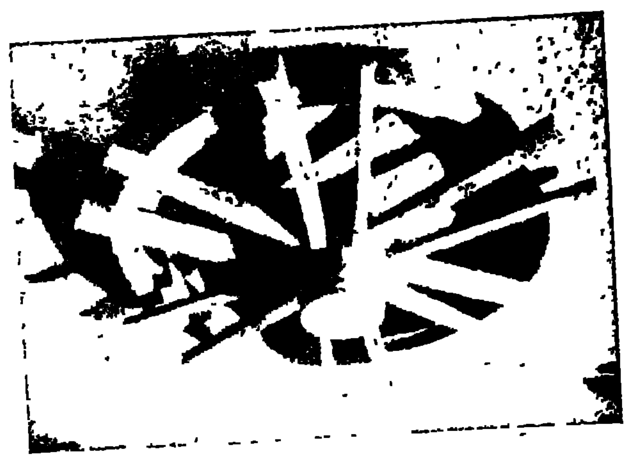
4
Tyre assembly. One section removed.



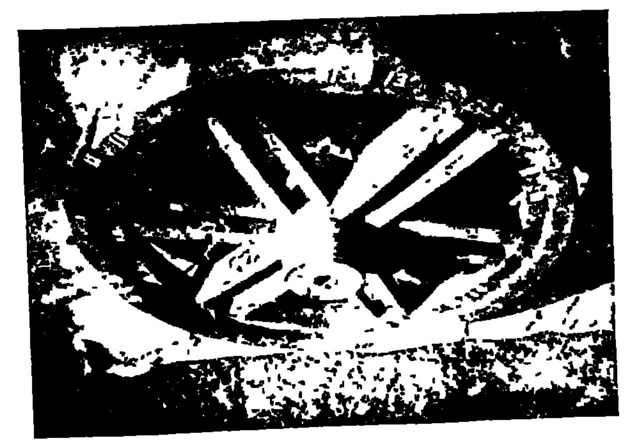
5
Six sections of wood tyre.



7
Notch housings cut in the stalk



6
Spider above tyre assembly for marking arms and stalk for cutting.



8
Spider with arms cut resting snugly in stalk housings

For convenience, let us call this first type of wheel the "arm" type, indicated by the letter A when referring to the experimental wheels described below

The main point about this A type "spider" is that the tight-driving of the arms in the hub, and the interpenetration of the arms among themselves result in the secure fixing of the arms. The idea is at least 3000 years old—as old as Harappa itself—and is, therefore, to be respected highly.

On the right in Photograph 1 is shown the other type of "spider", with radial spokes housed to a depth of about 3 inches in the hub, the alternate housings being staggered, from about an inch to 3 inches, around the circumference of the hub.

Without the modern Satanic (shrunk-on) steel tyre to keep the spokes well-pressed into their hub housings, this arrangement would be impossible, but tens of thousands of wheel-wrights have learned to build according to this principle, and they must be considered.

For convenience, let us call this second type of wheel the "spoke" type, indicated by the letter "S" when referring to the experimental wheel described below

Probably, over 95 per cent. of the wheels in Bihar are of the A-type, and so the improvement of this wheel was attempted first, experimental wheels 1 to 5, 7, and 8A having a main feature common to the construction of each.

The design keeps the A-type spider which is made in the village for about Rs. 5/-

The design scraps the steel tyre and the six sections of felloe, the twelve felloe wedges, and the six wooden dowels.

Instead, it adopts six T-shaped wood tyre sections shown in Photograph 2, and two mild steel flange rings, samples of which are shown in Photograph 3. In this last Photograph there are, on the left, a pair of flat-iron flange rings of 4 feet external diameter. Next, there are angle-iron flange rings of 4 and 3½ feet diameter respectively, and on the right, a flat-iron flange ring of 3½ feet diameter, and a pair of flange rings 3 feet in diameter.

Photograph 4 shows five wood tyre sections assembled, with the iron flange rings bolted to the sides of the stalk of the tyre, the sixth section having been taken out by undoing three bolts and nuts.

Assembly is simple.

First, the six T-shaped tyre sections are laid out as shown in Photograph 5, and one flange ring is bolted to the lower side of all the wooden stalks of the sections.

Next, as shown in Photograph 6, the A-type spider is placed centrally over the tyre assembly, a hole being made in the ground for the hub, and the wooden stalk is scribed for notches to be made to house the ends of the

arms The arms are also marked so that they can be cut off to the right length, to fit snugly into the notched housings in the wooden stalk

Photograph 7 shows the tyre and lower flange ring reassembled, after cutting the notched housings in the stalk.

Photograph 8 shows the spider with its arms cut to the required length, and bedded down snugly in the stalk housings Where the arms are not the full depth of the length of the housing notch, pieces of hard wood packing are fixed, each with a brass screw, to make up the full width of the stalk

Photograph 9 shows the upper flange ring bolted on, and the wheel then has its hub bored for the two iron liners or " arwuns ", after which it is ready for the cart and for the road, as shown in Photograph 10

It will be seen that the design complies fairly well with the necessary qualifications (i) to (iv) given on page 48.

The two flange rings, instead of one steel tyre, add a little to the weight and expense, but the flange rings are not subject to wear as in the case of the tyre and so they may be handed down from father to son, as is the agriculturalist carter's iron axle.

The weight of wood is somewhat more than that in the ordinary wheel, so as to allow for wear but the adoption of the angle-iron, instead of the flat-iron flange ring, may enable the thickness and weight of the wooden tyre to be decreased.

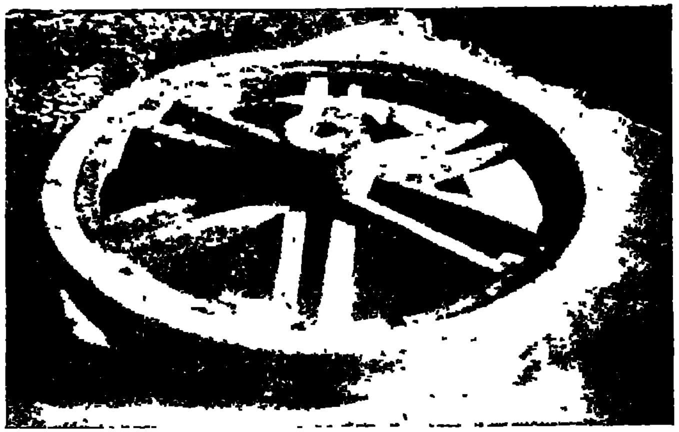
On the other hand, the wood tyre sections have no wedges or dowels, and so are easier and cheaper to construct and replace

Actually, the seven A-type wheels each have different minor features of construction so as to ascertain whether three bolts or two bolts per section, or whether 1/2 inch or 3/8 inch bolts are required

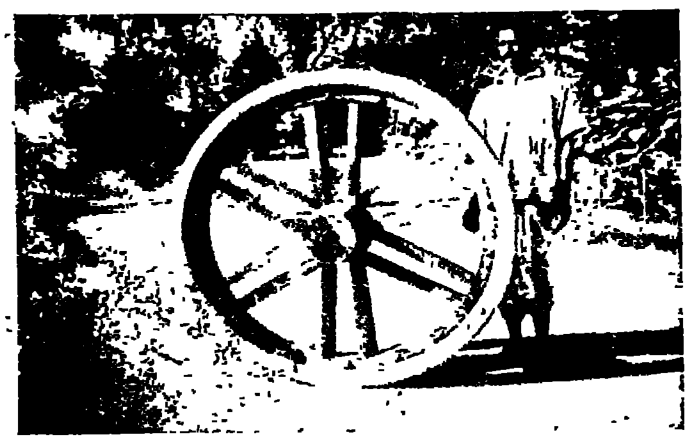
In one wheel, the stalk housings have been flushed with thick tar to ascertain whether this will improve durability and, in other cases, the side of the stalk and the inside of the flange ring have been painted with red lead or highly viscous tar before assembly to see if this will improve the grip of the flange rings on the tyre stalk.

The bolts have, variously, only one nut, a nut and lock nut, a nut and one or two spring washers, and so on to ascertain whether it is necessary to allow for expansion or contraction of the stalk in the monsoon or dry weather.

In this connection, a friend has recently suggested that the village wheel-wright will dispense with bolts and nuts by using heated short lengths of round iron rods as rivets in order to reduce cost. And the village wheel-wright will keep these same " rivets " for two or three replacements of the tyre, cutting off the [illegible] and making the wood stalk of the new tyre 1/8 inch less for each replacement in order to get 1/8

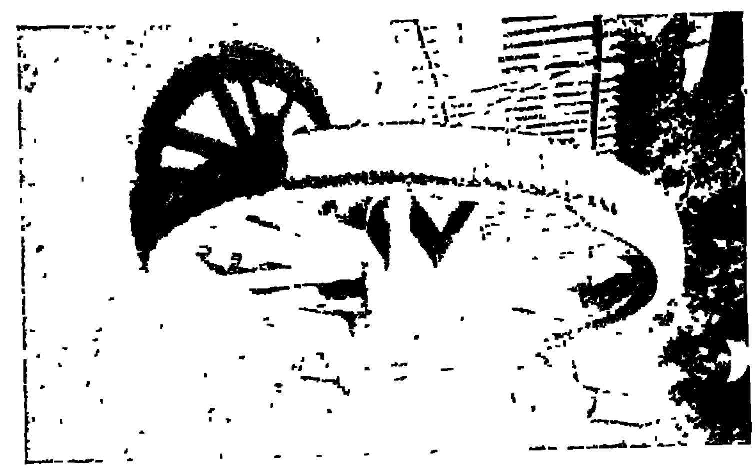


9
Top flange ring bolted on.



10
Wheel ready for the road.

11
Preparation of treads for treatment.



12
Preparation for impregnating.

13
Preparation for hotmix armour.

13 a
Applying hot mix armour.-Hot mix in "Karai" over an "ungaiti" applied with trowel and hammer,

14
6-inch tread reduced to 5-inch to give sloping sides.

inch of rivet to burr down and rivet Unfortunately there is no time now to get such a wheel made for test under wet and dry conditions.

These broad wooden tyres, varying in width from 6 inches down to $4\frac{1}{2}$ inches according to the size of wheel, are meant chiefly for the great alluvial tracts of India where, as road metal costs nearly a rupee a hat-full, the roads are chiefly of earth, and sometimes of kunker or burnt brick In these tracts, the density of population and carts is much greater than in the other rural districts.

But attempts are also being made with a view to helping the broad wooden tyre to stand up to metalled surfaces.

At the instance of our President one $4\frac{1}{2}$ feet diameter by 6 inch wooden-tyred wheel has been sent to the Alipur Test House for the impregnation and induration of its wood tyre with resin, under the direction of Dr. Sir Bhatnagar, the Director of Industrial and Scientific Research, and a similar wheel has been sent to the Test House for a covering of rubber incorporating coarse steel fillings.

The remaining wheels have sections made of different kinds of wood—sisam, jamoon, tamarind, sal, teak, mango and even simul, with a view to ascertaining which will wear best.

The soft woods have been tried because it is stated that, in the case of 'a grind-stone running with a steel axle in wooden bearings, the axle wears before the bearing, owing to the grit lodging in the softer material and thus wearing the steel that rotates against it.

It is hoped to apply this same principle to the soft-wood tyres.

The idea is to make the soft-wood tyre pick up road grit, and so arm itself against the road, rather than be worn out by the road.

On the left and on the right in Photograph 11 are shown sections of soft-wood tyre with saw cuts, about $\frac{1}{4}$-inch deep, across the tread with a view to impregnating the tread with tar and bitumen cut-backs, poured along the grooves after closing their ends with 20—30 penetration bitumen shown in Photograph 12 The spacing of the saw-cuts is varied in order to find which spacing gives the best impregnation.

A suggestion has since been received that it would be better to do the impregnation in the pressure plant used for "Ascu", or "boil" the sections of tyre in a fluxed bitumen or in tar in one of the large pans used for making *gur* in the villages. These methods would certainly be less messy.

A development from this idea is to give the wooden surface an armour coat by deliberately fixing Pakur stone chips on the tread rather than leave the wheel to pick up its own protective road grit. The wheel on the right of Photograph 11 shows a soft-wood tread, and the wheel in Photograph 13 shows a hard wood tread with some sapwood, both holed with a centre-bit and primed before being given a hotmix of 20—30 penetration asphaltic cement or high-viscosity tar and pitch.

It is hoped to have all these wheels at the next meeting of the

Roads Congress where those interested in their various experimental features may be able to see them and to read the full details of their preparation, the test sheets, and possibly some of the results of the tests.

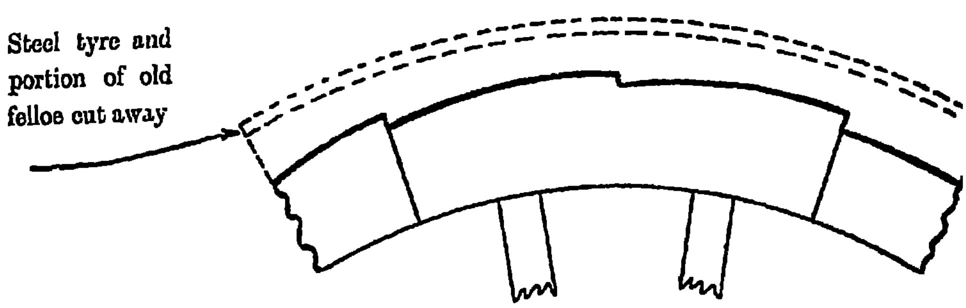
It has been stated, that owing to their great breadth and "sheer" or vertical sides, these wooden tyres will stick badly where the mud is deep.

Rai Sahib Lala Fateh Chand gave a memorable reply once to the effect that there ought to be no such persons as coolies. I would like to reply similarly, that there ought to be no such things as very muddy roads, and when the compromise tyre makes the low-cost road possible, there *will* be no very muddy *roads* !

However, Photograph 14 shows a broad wood tyre with one section of 6 inches wide tread and sheer sides, and the other five sections of 5½ inches wide tread with sloping sides The track of this wheel will be examined for variation of road suction.

The remaining desideratum, that the new type of tyre should be capable of being fixed to existing wheels, can also be realised Figure 15 shows an ordinary A-type cart wheel. On the right is shown an assembly of T-shaped broad woodtyre sections, with extra wide but thinner flange rings

In order to fit the new tyre to the old wheel, the old steel tyre is removed from the wheel, and the entire periphery of the old felloe is cut in a series of curved steps, as shown below.



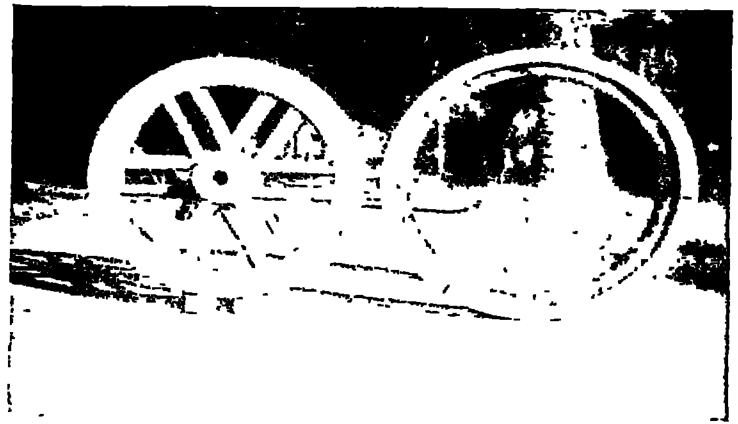
The tyre and flange ring assembly is then laid flat on the ground and the upper flange ring is removed The wheel is then placed centrally over the assembly, and the stalks of the assembly are scribed to fit the curved steps on the felloe. Then the stalk is cut to fit the felloe.

The wheel is then slipped into the tyre assembly, rotated slightly anti-clockwise till tight, and then small chips of wood are placed in the gaps between the riser of the curved steps before re-fixing the flange ring.

The ordinary wheel thus modified is called the R-type wheel, the letter indicating that the wheel has been remodelled. It is hoped to have this wheel also on view at the next meeting.

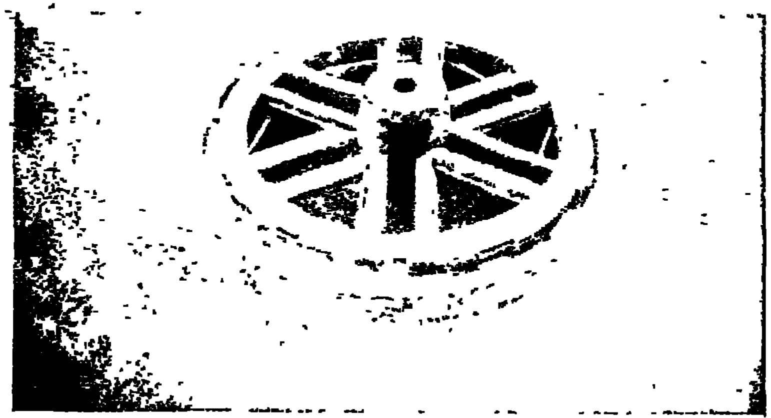
There remains the spoke, or S-type wheel.

If only some means could be found for keeping all the spokes pressed well home in the housings, the T-shaped wooden tyre and flange rings method previously described, could be used here also; but such means is not readily forthcoming.

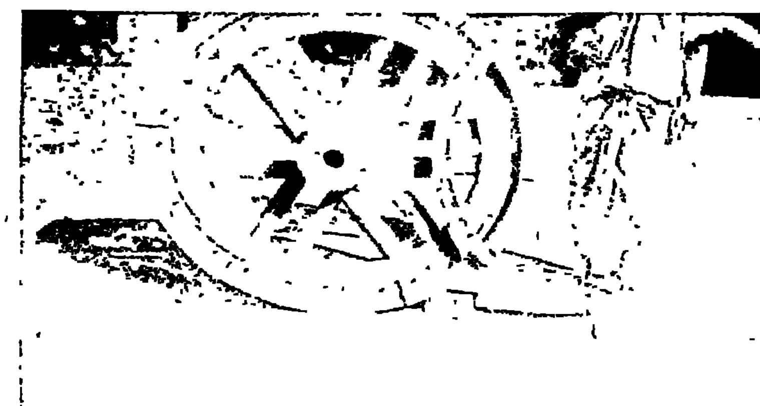


15
Conversion ordinary steel tyre to broad wood tyre.

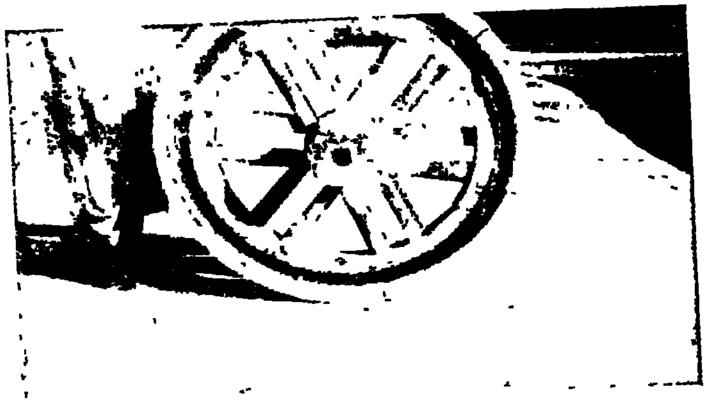
15 b
Conversion—Showing stalks scribed for cutting curved steps Rope and one ring hold assembly while scribing.



15 a
Conversion—Old wheel with stepped periphery placed centrally over assembly for scribing the stalks.



15 c
Conversion—Rope removed, stalks cut and reassembled, flange ring ready for bolting on.



15 d
Conversion—Wheel 6 R New tyre on old wheel complete.

16 a
S Type wheel—Flange ring with one section of tyre.
Cleats and wedges for spokes on alternate sides.

16
Different rim assembly for S-type spider.

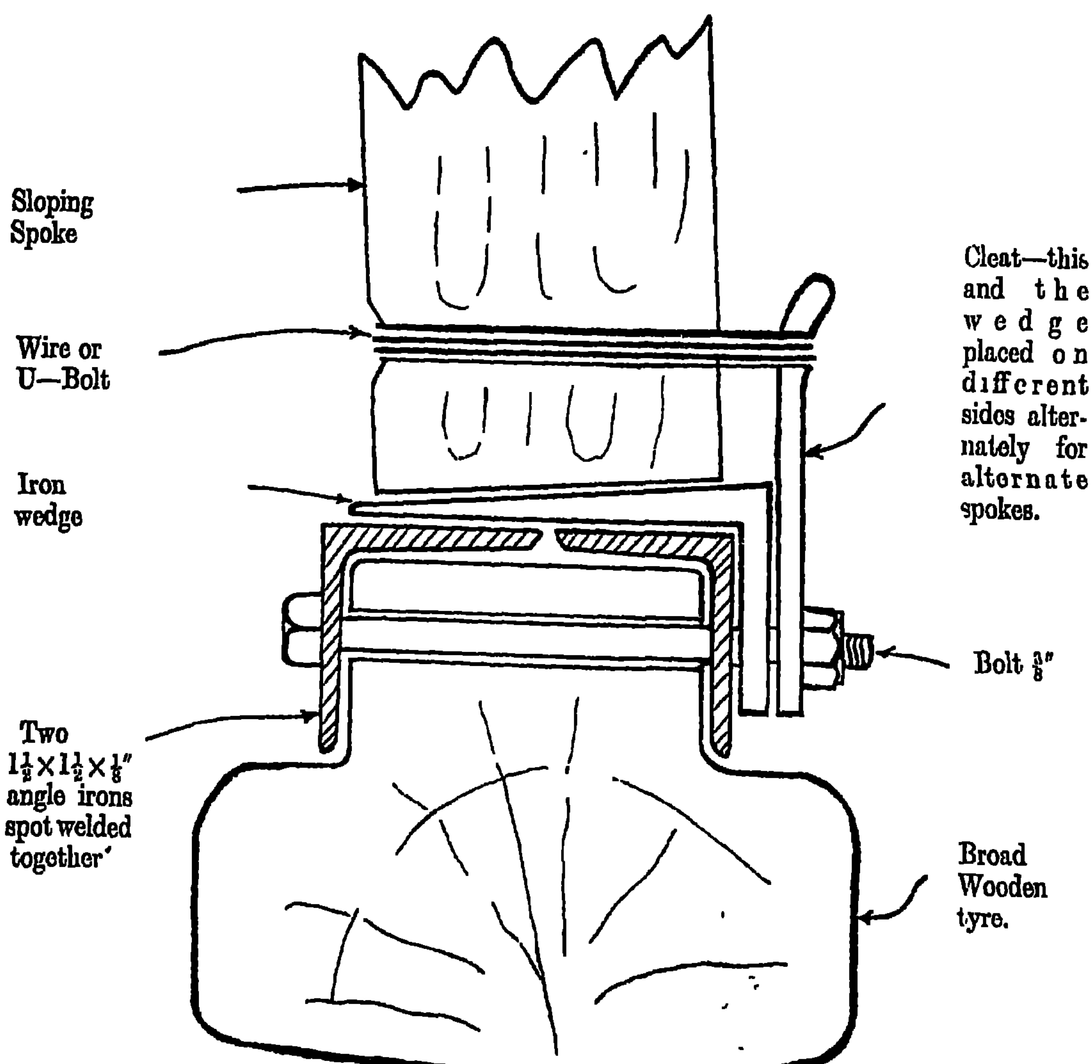
16 b
S type wheel completed with U bolts or wire.

One solution is that of "star-wiring", which it is hoped also to have on view. The system appears rather clumsy, so a new approach has been made to the problem.

Photograph No. 16 shows an entirely different form of flange ring. In this case, two $1\frac{1}{2}" \times 1\frac{1}{2}" \times \frac{1}{8}$-inch angles are spot-welded leg-to-leg, the T-shaped wood section used in Type A being held by bolts between the parallel legs of the angles.

A 3-inch channel iron could have been used, but it would be rather heavy.

For assembly, the tyre and flange ring are laid flat on the ground and the S-type spider is placed centrally over them, a hole in the ground being made for the hub. The spokes are then cut so as to fit inside the flange ring in which position they are held each by an iron cleat, wedge, and either a few turns of galvanised iron wire, or a $\frac{1}{4}$-inch diameter U bolt.



SECTION THROUGH TYRE.

The draw-back about this type is that, though there is no wear in them and they should last for many years, the twelve iron wedges and cleats constitute too many parts and add somewhat to the weight and cost.

Otherwise, all the five desiderata mentioned for the A-type compromise wheel are realised in the S-type also, though not quite so satisfactorily Perhaps members can suggest something

The cost of making each wheel has not been recorded as the labour could not be strictly supervised except on holidays, and some material was wasted owing to mistakes

But it will be evident that the untreated A-type will be more expensive than ordinary steel-tyred wheel by an amount approximately equal to the cost of one flange ring, the drilling of holes in the flange rings and the provision of the bolts and nuts, less a rupee or two owing to the T-shaped sections being much easier to make and fit than the ordinary felloes and their shrunk-on rim Roughly, the cost would be somewhat less than double that of the steel-tyred wheel, which latter in *Bihar* is from Rs 11/- to Rs 16/- according to quality, for a large steel-tyred wheel

When first they are seen, these compromise wheels give one the impression of being clumsy and heavy. As regards clumsiness, it will be remembered that, when we were all used to the sight of the high pressure pneumatic tyre, the new balloon tyres also looked clumsy It is all a question of what we have been accustomed to.

As regards weight, it may kindly be remembered that these wheels are only first efforts Helpful criticism, further models and experiments, and eventual standardisation and mass-production would doubtless result in the compromise wheel eventually being made considerably lighter than the ordinary steel-tyred wheel.

What a great help it would be to cartmen if the flange rings could be standardised in about 4 sizes, if the village "mistris" made and stocked standard wooden T-shaped sections, or if standard impregnated or compressed wood or jute fibre T-shaped sections could be turned out by organised industry more or less in the district headquarters town

There is a very important matter which might now be mentioned

The conclusions of the Indian Transport Advisory Council are, practically speaking, recommendations to all Governments in India, including the Central Government

This matter of improving the bullock cart wheel was discussed at some length in the 1941 Meeting of the Transport Advisory Council, and the Council recommended that "Experiments should be made with hard woods or other possible materials for wheel-rims".

Apparently, the only appreciable organised effort being made to invent compromise tyres is that of the Indian Roads Congress, its Council having offered a handsome honorarium, annually for three years, for the best practical design for a wheel to replace the steel-tyred bullock-cart wheel Also the Council has honoured the Author by financing the cost of his making a few wheels to demonstrate the A-type, R-type and S-type broad-tyred compromise wheel.

It is now suggested that there should be a standing "Bullock-cart Wheel Committee" which will consider the designs submitted during the above-mentioned competitions, and which, having chosen a few of the more likely designs, will get full-scale models constructed, tested, and reported upon. It is imperative that we proceed beyond the stage of writing, making sketches and talking !

In this connection it is submitted, with the utmost emphasis that the author of a paper can command, that this is no petty matter to be financed from the very slender resources of the Indian Roads Congress It is now stressed that the Transport Advisory Council has opened the door to the Roads Congress and that, war or no war, two crores of rupees wasted anuually is no mere bagatelle, and there must be a well-qualified well-paid technician working whole-time on the compromise wheel problem in consultation with the Bullock-cart Wheel Committee, all expenses being met by the Central Government, and not by the Roads Congress. The annual cost would be but a fraction of one per cent. of the annual receipts of the Central Road Fund. The finding of the compromise wheel capable of universal adoption in India would give the Central Road Fund a most startling and entirely new meaning.

It is time this Paper concluded, but would the reader please look again at the circle of waste—either the Author's or that prepared by himself

Out of the 85 papers read before our Roads Congress, 79 deal with waste-sector T, two touch on waste-sector P, and four—only four, those on pneumatic and compromise tyres and on track-ways—deal DIRECTLY with the waste-sector P.

It is now pleaded that more upholders of our slogan "Raise the Road : Rupee Ratio !" may, in future papers, break more ground in the waste-sectors other than T, notably in the waste-sector P

Closing this Paper, it is emphasised that the preventable damage to All-India's roads, which the Author rightly or wrongly puts at Rs. 2 crores annually, is but part of the great issue

The other part is that the universal compromise wheel will immediately make possible the goal of those of the Indian Roads Congress who have been working for the truly great cause of the low-cost road, (notably Messrs. S. R. Mehra, G. W. D. Breadon, C. L Chand, N. N. Ayyanger, T. G. F. Hemsworth and Lieut -Col. A. V. T. Wakely)—the low-cost road which was needed by the villagers long before the internal combustion engine was invented, and for which most of them, to say nothing of all the other road users, are waiting still.

Mr. N. V. Modak (Chairman) called upon Mr. W. L. Murrell to introduce his paper on "Raising the Road-Rupee Ratio with a special reference to the steel tyre" The above paper was taken as read.

DISCUSSIONS.

Mr. W.L. Murrell (Bihar) introducing his paper said:—if you have ever done anything unorthodox and waited, with mixed feelings of fear and curiosity as to the result of your own temerity, you will realise how anxious I am as to the way in which my paper may be received

In a meeting of technical men is it a crime or a service to suggest a "Constitution Suggestion Committee", or to propound a "Provincial Suggestions Committee ?"

It would be very greatly appreciated if anyone speaking on this paper would give his opinion so that, if the supporters of the proposals for such committees should prove sufficiently numerous, we might get on with the formation of these committees without delay

Turning now to the subject of the bullock-cart wheel, for which I ardently hope a third committee may be formed, I feel that I should have stated that the broad wooden tyre is meant for good, smooth, extensive road surfaces in cities, and well maintained surfaced highways, as well as for the low-cost roads of the great alluvial tracts of India

The tests made to date have shown:—

1. That the simple, flat-iron flange rings grip the sides of the wooden tyre better than the more expensive and heavier angle-iron flange rings.
2. That, with certain woods at least, there is very little swelling and shrinking across the grain, so that expensive bolts and nuts can be replaced by rivets made of round iron from the bazaar. In this connection, the Forest Research Institute, Dehra Dun, will be able to give very valuable advice as to any further experiments.
3. Viscous tar or bitumen placed between the flange rings and the wood tyre, and in the spoke housings in the tyre is good.

I would plead before this Congress that sufficient has been done to indicate that the broad wood tyre is an economically practical proposition, worthy of development by properly organised, large scale, further experiments carried out under a whole-time engineer.

In other words, it is time that the Government of India were approached to implement the recommendation of the 1941 Meeting of the Transport Advisory Council, that "Experiments should be made with hard woods or other possible materials for wheel rims". It would be for the proposed Bullock-cart Wheel Committee to act for the Indian Roads Congress in this matter

About 18 months ago, I prepared an estimate for Rs. 21,500 for the employment of an Assistant Engineer and staff for 9 months to

prepare 40 pairs of broad wooden tyres, and to test them on earthen, kunkar, mooram, brick metal, stone metal, and black top roads

The salary of an Assistant Engineer was to be Rs. 300 per mensem with a payment of Rs. 400 for the report

I now urge that the Central Government be asked to sanction this proposal and that this Roads Congress appoint a Sub-committee to control the work and to submit a final report to the Roads Congress

The urgency of the decision as to the final type or types of broad wood tyre to be adopted must be patent to all. We are all thinking of the programme of road development after the war. But we *must* realise that the actual specification of the projected roads depends on the *wheels* that will use them.

Will the broad wood tyre be developed to its final stage too late to affect the specification of roads for India's post-war programme ?

The wood tyred wheels brought to Gwalior are some of about a dozen which I constructed with financial aid from the Roads Congress. The idea in bringing them here is to encourage helpful criticism and suggestions from the members. George Stevenson built the "Rocket' but many have helped to evolve the modern steam locomotive

Mr. E. P. Nicolaides (Gammons, Bombay):—

With the steady and keen attention given to the improvement of the bullock-cart-steel-tyred wheel, Mr Murrell is by now an authority *on this subject and I am certain that his* valuable work entitles him to the gratitude of everyone interested in Roads and Road Transport

In his paper under discussion the author estimates that the steel-tyred-bullock-cart wheel causes to the Roads of India wear and tear costing annually some two crores of Rupees he considers this expenditure a preventable wastage heavily impairing the road-rupee ratio and he proposes consequently several interesting samples of wooden tyred bullock cart wheels which are intended to reduce considerably the annual expenditure on road maintenance.

That the wooden tyres will save to the P W. D road maintenance costs cannot be questioned and the relative amount of 2 crores estimated by Mr. Murrell is perhaps not far wrong; I may however be permitted to doubt if the manner of solving the steel-tyred wheel problem can be decided only by the financial benefits derived by the P. W D. It must not be forgotten always that the money spent on road maintenance is actually paid by the road using public and any scheme for reducing road maintenance costs either through improvements of the road or improvements of the vehicles can be financially warranted only if the same road-using-public which actually pays for the scheme gets also substantial financial benefits from it.

With this principle in mind it will be perhaps more correct to deal with a Road-Transport-Rupee Ratio instead of the simpler Road-Rupee Ratio.

Now in Mr. Murrell's proposals we may accept that the road-using public will save on one hand 2 crores of rupees annually; but on the other hand the bullock-cart owners who are the largest and cheapest agent of road transport will be asked to pay more for the initial cost, maintenance and replacement charges of their bullock-cart wheels

Mr Murrell estimates the cost of the untreated wooden tyred wheel to be about twice as much as a steel tyred wheel costing at present an average of Rs. 13/8/- each If the steel tyred wheels of a bullock-cart require complete renewal in say 10 years on an average, I think it would be fairly correct to assume that its proposed untreated wooden tyred substitute will not last more than half this period i. e. 5 years, considering the much heavier wear of wood as compared to steel.

This means that every 5 years the 6,500,000 bullock carts of India will have to spend about $2 \times 6500000 \times 2 \times 13.5 = 35$ crores of rupees, to change a pair of wooden tyred wheels, whereas with steel tyred wheels they would be spending half that amount in ten years. The extra annual cost of bullock-carts with wooden tyred wheels comes

therefore to $\frac{35}{5} - \frac{35}{2 \times 10} = 6\frac{1}{4}$ crores of rupees and it is certain that the

bullock-cart owners in this case will raise their charges proportionately making finally the road-using public to pay annually $6\frac{1}{4}$ crores of rupees more on their road transport.

Thus it will be seen that the wooden tyred wheel while saving 2 crores of rupees annually in road maintenance, is likely to raise the cost of transport by bullock carts by $6\frac{1}{4}$ crores of rupees annually and prove financially unwarranted from the point of view of the road-using public.

From the above considerations one may conclude as a principle that any substitute to the steel tyred bullock-cart wheel will only be warranted financially if it costs to the bullock-cart owners less in maintenance and replacement charges than the amount it saves in road maintenance. So long as this is not attainable it seems more economical to keep on spending on road maintenance and impose on the bullock-cart with steel tyres a tax proportionate to the damage it causes to the roads. Such a tax would come only to about Rs. 3/- per cart annually and should not prove a heavy burden to the cart owner.

Rai Saheb S K. Ghose (Bihar).

It is interesting to note that although this paper was written more than two years ago, the arguments put forward by the author for putting a stop to all forms of wastage on India's roads, have now an added force, in spite of the topsy-turvying effect of the Second World War.

In the denominator of the right hand expression for the Ratio, (page 43) perhaps it would be desirable to add D, the capitalized value of the lost lives and injured limbs on India's "dangerous" roads so that

We have it on the authority of Mr H. E. Ormerod (in Indian Roads, December, 1938, page 16) that the number of deaths from motor accidents in India is the highest in the world, and he pertinently observes, "There can be no safety when speeds maintained by various users of the road vary from 2 miles an hour to 60 miles an hour, on one and the same track". When there is *not enough road-width to accommodate* even a single lane of fast traffic, are we justified in trying to perpetuate the bullock-carts, by removing the steel from the periphery of the cart wheel, to inside the wooden rim? Would it not be better for the Indian Roads Congress to educate public opinion through the Press, against the positive injury being done by steel tyres of carts, and agitate for their gradual extinction? The animal-drawn cart, as a carrier of heavy goods, has disappeared from all other countries in the world except perhaps the East Indies and parts of South America. The modern tempo and speed of the world will not tolerate carts jogging along at two to three miles per hour, no matter whether they have steel or wooden tyres. Even in the superstition-ridden country, where traditions die hard, the *Push-Push*, the horse tram, and the camel cart, all have disappeared from our roads within living memory. Why should not the bullock-cart be cajoled to be a "good boy"? It should be rusticated by popular legislation. A strong Central Authority with the necessary sanctions could do it.

The absence of a Central Co-ordinating Authority led to the "Battle of the Gauges" in the Australian Railway system, as a result of which it takes only 4 days to cover about 3,000 miles from Melbourne to Perth with four breaks of gauges. The same diverging tendencies are noticeable in the many hundreds of authorities who are controlling the destinies of India's roads.

The Author's suggestion about publishing the different suggestions for improving the education of the Road Engineer in India should be given effect to by the Congress. The remarks made about the waste resulting from transfers from Buildings or Irrigation to Road charges are too true, and we should take effective steps to stop this system.

In this connection, I would seriously suggest the introduction of a "Student" class of membership of the Indian Roads Congress, so that the P.W.D., or District Board, or other roads staff, who have the necessary minimum qualifications, may have the benefit of learning correct methods and specifications etc by having easy access to the published literature of this unique institution which deals solely with road problems.

A Roads Research Officer is a crying need for co-ordinating the experimental work being done in the different provinces. In Bihar, for example, the "Roads Technologist" has not yet turned up, although he is long overdue. It is sincerely believed that the Author, whose strong views about the improvement of roads and road research in India are well-known to members of the Indian Roads Congress, will be able to persuade the Governments to remedy the long-standing defects in the system of Road Administration, now that he is at the helm of affairs, as the Chief Engineer of all Military Works in Bihar and also as a leading member of the Council in the Roads Congress.

This Session of the Congress will mark a turning point in the history of Roads in India, as it will have to chalk out the Post-war Road Policy

for India, and we must think thrice before we help to perpetuate the slow moving bullock-cart in the New Era of Speed and Progress.

Mr. V.N. Rangaswami (Burmah Shell, Madras) : —

Mr. Murrell, on page 45 of his paper, on "Raising the Road-Rupee Ratio" has referred to the Essay competition held, last year, on the subject of "training of the Road Engineer in India" He has rightly emphasised that, if we are to benefit by any such competition, there must be some agency by which any useful suggestions made by the competitors, can be collected, given the commendation of the Roads Congress and sent on to those who can give effect to these proposals. He has suggested, to this end, a "Provincial Suggestions Committee" which, I consider, is an excellent idea by itself. I am however afraid his proposal to forward the suggestions of this Committee to educational institutions will not have the desired result. It is extremely unlikely that these institutions will take any prompt initiative in the matter. For example, copies of the I.R.C. bulletin No. 5 (1942) were sent by me to the Director of Public Instruction, Registrar of the University, and Principals of the Engineering Colleges, in South India and the subject-matter was discussed with some of them. To the best of my knowledge, however, nothing has been done so far to revise or expand the curriculum in Highway Engineering nor to start a special course in Highway Engineering, as suggested in the Essay. It is paradoxical that whilst, it is possible, now-a-days, for a young man in this country to find facilities for training in the more recently established branches of Engineering such as Automobile Engineering, Aeronautical Engineering, Wireless Engineering etc., there is no institution where an aspiring road engineer [on whom so much depends to increase the Road-Rupee Ratio] can get training for the time-honoured profession of Telford and Macadam. I suggest, therefore, that rather than leave the question of stimulation and propaganda in the hands of the "Provincial Suggestions Committee" or at the mercy of provincial institutions, the Congress set up a Sub-committee to review the position of "technical education of the road engineer" in India to-day It should then forward its recommendations to the Government of India with a request that they establish, to start with, a Chair of Highway Engineering at one of the Indian Universities or at the Indian Institute of Science at Bangalore where courses in Wireless Engineering, Aeronautical Engineering, etc., exist now. It might be argued that the question of providing the necessary finance for such a Chair might be a problem. I, however, venture to suggest that a contribution from the Reserve in the Road Fund for this purpose would be an appropriate form of expenditure for which this fund has been constituted. I would also like to commend for your consideration that such a Chair might be appropriately named "Sir Kenneth Mitchell Chair of Highway Engineering" in recognition of the services rendered by Sir Kenneth to roads and road engineering in India in the same way as the "Sir Henry Maybury Chair of Highway Engineering" in the Imperial College of Science, London, was instituted to commemorate the services rendered by Sir Henry Maybury to Highway Engineering in the U.K. I hope the Council of the Congress will give this subject matter their earnest and immediate attention as the question of providing trained personnel, for any Post-War Road Reconstruction plan, is a matter which should receive our attention here and now.

Mr. Kynnersley (Concrete Association, Bombay) :—

Mr. Murrell has already been congratulated on producing this valuable thought-provoking paper and I feel that his suggestion that immediate funds be made available by the *Central Government to this Roads Congress* for the specific object of putting into effect the suggestions of the Sub-committee appointed to deal with this matter which may be either for more experimental work on a wheel or for the manufacture and presentation of a small number of carts fitted with special wheels to Provincial rural authorities who would see these carts were used and tested methodically and who would send in detailed reports within a given period of time

There is one suggestion, I would like to make to Mr Murrell in connection with the shape of the rim portion Would it not be better to cut back the sides of the rim portion to give a small clearance angle to avoid friction and suction in clayey and muddy areas ?

Mr. M.A. Rangaswamy (Bihar).

Mr. Murrell has, indeed, done yeomen service to India, in focussing the attention of all Engineers of the Roads Congress to the need for minimising the 'wastage' occurring under different heads in order to increase the Road-Rupee Ratio, or in other words, to make the Rupee run the longest

Mr. Murrell has made very valuable and interesting suggestions in his paper to reduce the wastage One may not agree with him, as he himself admits, in the division of wastage represented by the circle, but none would disagree with him in admitting the wastage.

Sectors A & E are more or less co-related. Wastages under these two heads can and ought to be eliminated or minimised

Administration of roads including the training of the staff to construct and maintain them, should be in the hands of a professional organization—outside the sphere of politics That can only be achieved by the Congress setting up a Committee (as suggested by the author) which will influence the powers that be, who will have a hand in the shaping of the constitution for India.

The constitution suggestion Committee, or the Administration Committee, can easily be the Council of the Indian Roads Congress. This Council should appoint a Sub-committee out of the members to the Roads Congress for each Province, and States, to collect and advise the Council on matters relating to the training of the Engineer, conditions of employment of Engineers and last but not the least, the provincialisation of the services of District Engineers Except in Madras, the District Engineers are always under the fear of insecurity and many will heave a sigh of relief on drawing the pay of the previous month To every District *Board in Bihar, funds from Motor Vehicle and Petrol taxation are given* annually by Government; this sum could be retained by Government to provincialise the services of District Engineers and release the Boards the responsibility of financing the Engineers' pay; I daresay, every District Engineers all over India (excepting in Madras Presidency),

should be voicing their feelings of gratitude to Mr. Murrell, for his ably championing their cause, whenever opportunity arose for him.

Under Sector T & P, the suggestions offered by the author for improvement could be considered by the Council, whose technical Sub-committee could do the needful with the assistance of Provincial Sub-committee.

The need for improvement of the wooden wheel of the bullock cart is very pressing, and there should be a Central Committee set up by the Congress particularly to develop research in the field of improvement of the cart wheel. There should be a whole-time technical officer for this purpose and the suggestion of the author, in this respect, is excellent.

Sir Kenneth Mitchell in his Presidential address to this Congress has also very strongly drawn the attention of the members to the need for improvement of the position, and it is hoped that the Congress through its Council will take up the matter to reduce this administration wastage.

Mr. Murrell (Author) :—

I am grateful for Mr. M.A. Rangaswami's appreciation of the paper. It would seem at least that he agrees with the suggestion for a Provincial Suggestions Committee, and with the proposal to conduct a final experiment under a whole-time Engineer.

Mr. V.N. Rangaswamy thinks that while it is a good idea to have a Provincial Suggestions Committee, the sending of suggestions to educational institutions would not have the desired effect. The reason lies in the apathy which many such institutions exhibit towards any suggested improvements in the civil engineering curriculum.

Mr. Rangaswami suggests that a Sub-committee be formed in the Indian Roads Congress to report the situation to the Government of India with a suggestion that they establish an All-India Centre for Institution in Highway Engineering, the cost being met from the Central Road Fund.

The idea is an excellent one and is strongly recommended to the Council.

Unfortunately, Mr. Nicolaides appears to be unaware of what has been done already in attempts to tax bullock-carts. About two years ago, the All-India Association of Local Self-Government Bodies chose Patna as the venue of their annual meeting. My paper submitted to this meeting was keenly discussed but no decision was arrived at. A few months later, a meeting of the Chairmen of all Bihar District Boards decided by a bare majority not to tax carts.

Mr. Nicolaides does not appear to know the ways of District Boards. Even if they decided to tax their carts, it would not necessarily follow that the proceeds of taxation would be devoted to roads.

I do not quite understand the remarks of R.S.S.K. Ghose concerning the question of improving the Road-Rupee Ratio. I am afraid I do not agree with the Rai Sahib's proposal to dispense with bullock-cart.

No. 1

Average condition of Moorum road during rains specially where drainage is defective.

No. 2

Coolies repairing ruts in moorum road.

No. 3

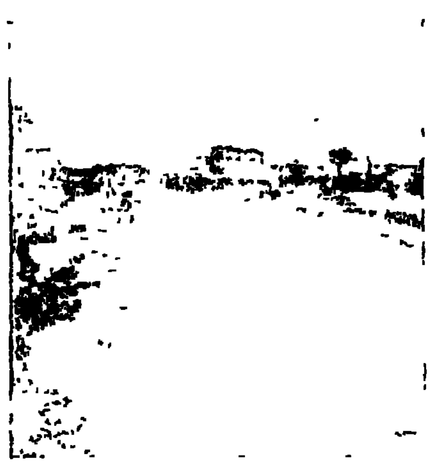
Moorum spread to Camber before consolidation.

No. 4

Soling stones exposed by heavy

No. 5
These roads carry more bullock carts than "Adlers".

No. 6
Looks like good macadam road but is really a well kept moorum road.



No. 7
Sho[illegible] [illegible] painted surface e[illegible]es —Mile 27[illegible].

No. 8
Shows patch repairs done with premix—Mile 28/I.

No. 9

Shows 1″ Carpet breaking at edges —Mile 32/IV.

No. 10

1″ Carpet that has stood the ravages of bullock carts near Potka Police Station.

No. 11

Another view showing the excellent surface with 1″ Carpet—Mile 29/[illegible]

No. 12

Another stret[illegible]

[illegible] for about a [illegible]

PAPER No. D—41

SOME EXPERIMENTS TO STABILISE MOORUM ROADS IN CHOTA NAGPUR

By

K. Gupta, B.E., A.M.INST.C.E., A.M.I.M. & Cy.E.,

District Engineer, Singhbhum, Chaibasa.

Chota Nagpur is a small Division in Bihar, having a total population of 6,643,938 an area of 27,117 square miles and 5,186 miles of roads. It will be seen from Table I, that a very small percentage of the lengths of roads maintained by the District Boards are metalled.

How the unmetalled roads give off dense clouds of dust, become boggy during the rains, and cause inconvenience and discomfort to both slow and fast traffic, is well known to the public as well as to all Road Engineers.

The main source of income of the District Boards is the local cess supplemented by Government grants besides a small income from pounds, ferries, etc. But in actual practice, a large percentage of this income is diverted to purposes other than the maintenance of roads. It would not be out of place to quote in this connection the observations made by the Government of Bengal, on the working of the District Boards in Bengal :—

"It appears that the District Boards have not been able to resist the temptation of reducing expenditure on communications in order to find more money for what are generally regarded as popular services such as medical relief, sanitation, etc.

Without minimising in any way the importance of these services, Government desire *to take this opportunity of impressing upon the District Boards that the* prosperity of the district depends very largely on the maintenance of adequate communications, and the grant of Public Works Cess to the Boards has entailed a moral obligation on them to devote correspondingly large sums to projects which have previously been financed from this cess, with a view to developing the economic resources of the rural areas."

Probably the same observation may be made for the District Boards of Bihar. At least the figures given in Table II below, for the Singhbhum

TABLE I.

District in Chota Nagpur Division in Bihar.	Milage of Roads: Maintained by P.W.D.: Metalled	Milage of Roads: Maintained by P.W.D.: Unmetalled	Milage of Roads: Maintained by District Board: Metalled	Milage of Roads: Maintained by District Board: Unmetalled	Milage of Roads: Maintained by District Board: Village Road (a)	Percentage of metalled length to total milage: P.W.D.	Percentage of metalled length to total milage: D.B. (b)	Expenditure on unmetalled roads of District Board: Total in Rs. (c)	Expenditure on unmetalled roads of District Board: Average per mile in Rs.
1. Manbhum ..	256	—	172	701	507	100	19·7	56,582	80·7
2. Hazaribagh .	160	16	156	597	287	90·9	20·7	25,575	42·9
3. Ranchi ..	153	47	56	574	201	76·5	8·9	32,266	56·2
4. Singhbhum ..	76	—	9	532	30	100	1·6	43,395	81·6
5. Palamau ..	55	—	73	451	47	100	13·9	1,15,555	256·2
TOTAL ..	700	63	466	2,855	1,072	—	—	Average	102·0

(a) Village roads are neither bridged nor surfaced

(b) Village roads are excluded

(c) Figures relate to the year 1937-38 and include expenditure on construction and repairs to bridges and culverts.

District Board where the author is working as a District Engineer, show this very clearly.

Year under review	1938-39	1939-40	1940-41
Amount of Cess in rupees ..	1,24,000	1,25,219	1,16,162
Allotment of Cess to Civil Works* in rupees.	1,02,303	93,051	72,780
Percentage of allotment to Cess. .	80·9	74·3	57·3
Total income of the Board in rupees	4,37,209	4,55,019	4,38,360
Total allotment to Civil Works in rupees	2,18,477	1,94,985	1,79,485
Percentage of total allotment to total income	49·9	42·7	43·2

Of course, besides the above, some Boards receive substantial grants from the Central Roads Fund, mostly for new road projects and bridges. If, however, more funds were available from the Central Roads Fund for improving the surface of existing unmetalled roads and maintaining them, there could be more widespread development

It may be seen, from the last column of Table I, that an average of Rs. 102/- only is available per mile of road, for maintenance, improvement of surface, and also for construction of bridges and culverts With this poor sum, metalling is definitely out of the question, and even proper maintenance of the road with a gravelled surface, is not possible. No doubt the district or secondary roads which are maintained by the District Boards have been more or less neglected in the past; but owing to the rapid increase of motor traffic, which is penetrating deep into the interior of districts, for quick transport of merchandise and passengers, the condition of these roads, which were never meant for such fast or heavy traffic, can be described as dangerous. If the prosperity of the district is desired, these roads can no longer be left uncared for, to go to wreck and ruin and be rendered useless for any kind of traffic.

It is, therefore, necessary to search all avenues, first, to augment the finances for road work and, secondly, to find out the cheapest practicable methods of making a road surface that would stand up to the modern traffic.

* (This includes allotment for establishment and for works on Roads, Buildings and Water Supply.)

The experiments carried out by the author which are the subject matter of this paper are attempts towards the second object

Materials available for Road making.

Present day traffic demands that the road surface should at least be stone-metalled and have a wearing coat of tar or bitumen.

Chota Nagpur is a hilly tract and good road metal is available almost everywhere within a reasonable distance. *Even then the cost of metalling* and seal coating with Road tars No 1 and No. 2 is not less than Rs 14·64 per 100 square feet, vide Appendices I and II, pages 69 and 70

This tract is, however, blessed with another road material, known as Moorum, found in abundance in Nature

This moorum is a ferruginous gritty matter, reddish in colour consisting mainly of particles of quartz (sometimes associated with more or less altered felspar) of size ranging from 1 inch down to the size of a pea, sand and ferruginous clay. This clay serves as a binding material for holding the particles together *It has been observed* that moorum is generally free from harmful salts.

This material when wetted and compacted on the road and allowed to dry, forms a hard crust and can withstand light traffic.

Most of the unmetalled roads in Chota Nagpur are surfaced with moorum which is either laid loose, or consolidated as funds permit.

The usual methods of surfacing with moorum are briefly described here.

1 *Making a surface with loose moorum.*

Moorum collected on the roadside during the summer (towards the end of monsoon is spread) on a 9 to 10-feet width of the road to an average thickness of 6 inches, directly on the subgrade to a camber of 1 in 30 without any base or soling. Traffic is then allowed on the road, which presses down the moorum to some extent. The surface is dressed from time to time as wheel ruts are formed. For repairs to an existing moorum surface, an average thickness of 3 inches of moorum (after filling up the wheel ruts) is spread and treated in the same way. During the rains, the moorum, being wet, sticks to the damp subgrade and becomes hard on drying after the rains

2. *Making a surface with moorum, rolled and consolidated.*

The procedure is the same as in the case of loose moorum, with the difference that, after spreading the moorum, it is wetted if not already wet, and rolled with a 2 to 3-ton hand roller. The edges are protected with grass sods to prevent the moorum from spreading out For repair works on an existing moorum surface, the existing surface is picked before fresh moorum is spread. Traffic is not allowed on the surface, during the process of rolling and till the consolidated moorum is dry and hard.

Behaviour of moorum surface under wheeled traffic

When the moorum is left loose and gets wet and boggy, due to the presence of sand and stone particles in it, the wheels do not get stuck or skid as in clay. Once the surface is well consolidated and has become hard on drying, it resists to some extent the soaking of water into the subgrade from above, and if the subgrade is not bad, it really provides a good riding surface (*see photo No. 6*), even during the rains. Due to absence of sufficient binding material, or being dry, moorum, which has not set on the road, is blown off by fast traffic, and the heavier materials settle down and form ridges on both sides of the wheel tracks, thus producing two parallel ruts. During rains these ruts function as water courses and are gradually deepened, very often exposing the subgrade. Bullock cart wheels with steel tyres then play the worst part by cutting into the subgrade, which, due to the soaking of rainwater, becomes soft and causes all sorts of trouble. Even when consolidated, the constant moving of wheels wears down the hard crust quickly forming shallow wheel ruts. The case is very much worse when there is mixed traffic of steel-tyred carts and pneumatic tyred motor vehicles, the former cutting, loosening and crushing the stone particles and the latter blowing them off the road in the form of dust. As soaking of water through the moorum surface is not altogether stopped, bad subgrades soften and yield under heavy load and become boggy. To stabilise such bad and yielding subgrade, the usual practice in the district of Singhbhum, is to put in a 6-inch layer of soling stones over the whole width of roadway with two lines of edging stones 10 inches deep and 4 inches thick. This is expensive and has a further disadvantage that the stones, however well packed, move about under the roller during consolidation of moorum, or under the action of the wheels, the heavier ends going down into the subgrade and the lighter ends sticking upwards. A large quantity of moorum disappears within the interstices and below the irregular shaped soling stones, and more blinding material is required to produce an even surface. Again, probably due to not adhering to the stones, the moorum is washed off the stones during the rains exposing a very uneven surface (*see photo No. 4*).

Observing some of the good properties of moorum, specially when well consolidated over a good subgrade, the author considered that if the moorum surface could be directly treated with a seal coat, or a wearing coat of tar or bitumen, the expensive item of macadamising such roads with hard metal might be entirely dispensed with

With this object in mind, the author communicated with some of the firms dealing with road tar and bitumen, for their opinion in the matter. No hopes were given by tar dealers, but Messrs. Standard Vacuum Oil Company after making some laboratory tests on the samples of moorum sent by the author, expressed their opinion that asphalt cutbacks or emulsions might suit moorum, and deputed their Road Engineer to examine the problem jointly with the author. A specification was then decided upon to suit the conditions at site.

The District Board of Singhbhum was good enough to sanction a sum of Rs. 2500/- to carry out a series of experiments on some of their roads.

The following experiments were then conducted by the author who was hampered in his work for want of skilled labour, but the results

obtained clearly prove that further work on these lines may prove more successful elsewhere

Experiment Nos. 1 to 11—Surface painting with Asphalt.

I MATERIALS .—

1 Asphalt—Although it is presumed that all Road Engineers are more or less familiar with different grades and use of Asphalt in road works, a brief note on the grades used in the experiments will not be out of place

Cut back* is a solution of comparatively hard grades of Asphalt in a volatile solvent. After exposure to atmosphere and traffic conditions, the cutback loses its volatiles and settles down as a hard sticky substance. Liquid Asphalt* is the softest commercial grade of asphalt with or without a solvent Emulsions* are intimate mixtures of asphalt and water, asphalt being held in suspension in water with an emulsifier or stabiliser to counteract the settling propensity of asphalt This stable emulsion, however, breaks down on exposure to air when the water gradually evaporates

These grades of asphalt are used on the road without prior heating

The author used the following grades of asphalt supplied by Messrs Standard Vacuum Oil Company in 40 gallon drums containing about 440 pounds of asphalt each.

Cut backs—	(i)	Socofix Primer containing about 55% of bitumen,
	(ii)	Socofix containing about 80% of bitumen,
Liquid Asphalt—	(iii)	Liquid asphalt No 2 containing about 70% of bitumen,
Emulsion—	(iv)	Socony Emulsion No. 3 containing about 50% of bitumen.
2 *Sand*—		Clean sand (screened through 1/8 inch mesh screen) was obtained from Gura river near mile post 32 of Tiring Matigara Road
3 *Aggregate*—		Washed moorum retained on 1/8 inch mesh screen was collected (as this was locally available and was very much cheaper than stone chips)

*Definitions proposed by Technical Sub Committee to be accepted as Indian Roads Congress Standards

Cut back bitumen is Bitumen which has been softened by oil sufficiently volatile to evaporate with time

Asphalt is a natural or artificial mixture of bitumen and mineral matter

Road Emulsion A suspension in water of a bitumen, or tar, or of bitumen and tar in a finely divided state, stable for the purpose of storage and transport The proportion by weight of bitumen or tar or of bitumen and tar should always be specified.

II. TOOLS AND PLANT:—

The following tools and plant were used :—

		Nos.
1.	Shovels . ..	4
2.	Pick-axes	6
3.	Spades	6
4.	Template for checking camber ..	1
5.	Hard brush	6
6	Soft brush .. .	6
7.	Wire brush	6
8.	Country Brooms	4
9.	Baskets	12
10.	Empty kerosene oil tins	4
11.	Jhajri or locally made sprayer ..	4
12	Screens—1/8 inch mesh	1
13.	Spanner for opening bungs of drums ..	1
14.	3 tons Hand roller ..	1
15.	3 bundles of Moonj or grass rope.	

III. SITE :—

It was decided to make the experiments on Tirin Matigara Road in *short lengths where the surface was hard and had a good camber,* so that no extra expenditure would be necessary for re-conditioning the surface.

IV. PROCEDURE :—

Two coats of painting with the following combinations of different grades of asphalt were tried

(a) A coat of Socofix over a priming coat of Socofix Primer or Liquid Asphalt No. 2.

(b) A coat of Liquid Asphalt No. 2 over a priming coat of same.

(c) A coat of Emulsion No 3 over a priming coat of same or Socofix Primer.

When the materials were ready at site the following operations were carried out :—

1. *Cleaning the surface.*—The surface of the road was at first brushed with wire-brushes to remove any loose moorum and dry cow-dung, then with country brooms and finally with soft brushes, till the surface was free from all dust and loose moorum.

2. *Kerbing.*—An edging 6 inches wide and 3 inches high on both sides of the roadway leaving a space of 9 feet, was then made with roadside earth to prevent the asphalt from spreading out.

3. *Measurements of the materials were made with empty kerosene oil tins.*—Half a tin of asphalt measured 20 pounds or 2 gallons, and one-and-a-half tins of moorum or sand measured one cubic foot.

4 *Diversion.*—No traffic was allowed over this portion of the road during the progress of work. Barriers were put at both ends and traffic diverted along the flank of the road

5. *Priming Coat*—A length of road was marked off to give an area 100 square feet approximately. The Primer was then taken in a *jhajri* (made of an empty kerosene oil tin with perforation on one side for half the height of the tin from top and wooden handle, *see fig 1*) and poured on the road surface along its length beginning at the centre of the road and ending at the edges. While asphalt was being poured, two men spread the same evenly with hard brushes having long handles

6 *Blinding the priming coat.*—Measured quantity of sand or moorum was spread on the painted surface with a whirling motion with a spade. Even-ness of the thickness of blinding material was, however, ensured by throwing extra material in handfuls where it was thin.

7. *Second Coat.*—After the priming coat, an interval depending on the grade of asphalt used was allowed. Second coat of asphalt was then applied in the same manner as the first coat, after brushing off any loose sand or moorum used as blinding to the priming coat.

8 *Blinding the Second Coat.*—This was also done in the same way as in the case of priming coat.

9 *Opening the road to traffic.*—The road was opened to traffic after about a fortnight of the second coat when the surface was found hard.

Details of these experiments and details of the quantities of asphalt, blinding materials used, interval between the two coats etc, are given in Table III (*For costs vide Appendices III & IV*).

Experiments Nos. 12 to 18 with 1 inch Premix Carpet of Asphalt

I MATERIALS required were the same as in the case of surface painting, except Liquid Asphalt No. 2

II TOOLS AND PLANT—Same as before.

III. SITE—Tirin-Matigara Road.

IV. PROCEDURE :—

(1) *Cleaning the Surface.*—This was done in the same way as before.

(2) *Kerbing.*—No kerbing was put as protection to the edges.

(3) *Diversion.*—This was made as in the previous case.

(4) *Priming Coat.*—Two lines of Moonj rope were stretched along the length of the road at a distance of 9 feet, and two lines across the road at a distance of 11 feet 2 inches defining each unit of 100 square feet of road surface, where carpeting was to be done. A priming coat of Socofix Primer was then applied on only one foot width at each edge, instead of the whole width. No blinding was done.

(5) *Premix.*—Measured quantities of sand and washed moorum consisting of stone particles of sizes ½ inch to ⅛ inch were kept separately. Asphalt was then taken in a jhajri and poured over the moorum as a thin film over the exposed surface of moorum, the top layer of moorum was then removed to one side with the help of a *kodali* and a fresh surface exposed. This was then coated with a thin film of asphalt, and then removed, the process was repeated till the moorum was exhausted. Then a thorough mixing was done with the help of a spade by turning over the moorum several times. While this thorough mixing was done, sand was gradually added where the mixture was to be of sand and moorum.

(6) *Carpeting.*—When the above mixture or the premix became slightly sticky due to evaporation of the solvent and settling down of the asphalt, it was spread on the road surface to a thickness of 1½ inches to 2 inches so as to have a camber of 1 in 54 which was checked with the wooden template. The premix, spread over the road surface, was then consolidated with a 3 ton hand roller after an interval of 24 hours, when it was compacted to a hard crust of about 1" thickness. The road was opened to traffic after about a fortnight by which time the carpet had become hard.

(7) *Sealing the Carpet.*—After allowing the traffic for some time the carpet was given a thin coating of asphalt and blinded with sand. Traffic was closed on this portion of the road for about two days after the sealing was done.

Details of experiments with quantities of asphalt, sand, moorum, etc., are given in Table IV.

Behaviour of Treated Surface.—

Experiment Nos. 1 to 18 were carried out in the month of May 1940 and the sealing to the Premix Carpet was done in December 1940, by which time the following defects were noticed in the painted surfaces.

(1) In lengths where twocoat painting was done, rain-water collected near the edges due to bad drainage, and crept under the painted surface and softened the base. At these places the

cutting action of the steel-tyred bullock-cart wheels severed pieces of the hard crust of bitumen and moorum from the main body and made pot-holes.

(2) Liquid Asphalt No. 2 which has an oily carrier, did not harden for long, and every cart-wheel made a deep impression on the surface

The road flanks were dressed to have an adequate outward slope to prevent rain-water collecting near the edges, and a water-proof edging was given on both sides of the treated surface to prevent the creeping of water below it.

Grooves 2 inches wide and 4 inches deep, were cut along the edges and filled with a premix prepared with 12 pounds of asphalt for every two cubic feet of washed moorum and one cubic foot of sand. Before filling in the premix, the grooves were painted with Socofix Primer or Socony Emulsion No 3 at the rate of 30 pounds of asphalt for every 100 square feet of the surface.

The pot-holes were also similarly filled up with premix after clearing them of all dusts and loose particles and giving a priming coat When the premix hardened after about 24 hours, it was rammed well

The surface that had a carpet of 1 inch premix stood very well. These places also were given a water-proof edging similar to the places where surface painting was done.

In the month of January 1941, *i.e.*, after a month of the above repairs, it was noticed that pot-holes were forming at other places of the painted surfaces, although the repaired portions remained intact

This gave an impression that surface painting does not suit the moorum surface and that a premix carpet is suitable So some more lengths were given a premix carpet and for further comparison, another length of 230 feet was given a two-coat painting, and their behaviour watched. At these places, an edging of premix was put along with the carpeting and surface painting

The details of the later experiments Nos. 19 to 22 of Premix are given in Table. IV, and that of the surface painting experiment No 23 in Table III.

The present conditions of all these treated surfaces are stated in these tables, and these will show that the previous opinion formed about the surface painting does not hold as although most of these have failed, some are faring very well It is, therefore, apparent that there is some factor that makes the treated surface stable or unstable in the case of surface painting.

The author, therefore, arranged for some analyses of the moorum, specially the sieve test The results obtained are given below in Table V.

TABLE V.

	Percentage of Grit contents					
	Gravel	Sand			Silt & clay	Total
Passing through Mesh No. and retained on Mesh No.	— / 10	10 / 40	40 / 80	80 / 200	200 / —	
Stable* Moorum-Sample No 1	61·6	27 1	5·9	3·0	2 4	100
Stable Moorum-Sample No. 2	60·7	33 6	3·8	1 0	0·9	100
Unstable* Moorum-Sample No. 1	31·1	37·8	14 3	10 5	6·3	100
Unstable Moorum-Sample No. 2	46 1	44·3	6·2	2·3	1·1	100
Unstable Moorum-Sample No. 3	43·3	42·4	8·2	3·3	2·8	100

The above table indicates that the percentage of grit contents of moorum retained on No. 10 mesh has something to do with the stability.

In one case (Experiment No. 21) the premix carpet has failed but this, the author believes, is due to a number of steel-tyred bullock carts passing over the surface, cutting and disturbing it very badly before it had time to harden.

The cost of surfacing a road with moorum and treating it with asphalt, in this district, is Rs. 8 5 per 100 square feet (*see Appendices III & IV*). This compares favourably with the cost of metalling the surface with stone (Rs. 10.21) (*See Appendix I*).

CONCLUSION

This paper had been written with the object of focussing the attention of engineers to the problem of low-cost roads, and the author believes that under favourable circumstances and improved methods, it may be possible to maintain moorum, gravel and earth roads with an artificially hardened crust at very much less cost than the usual water-bound macadam surface, and he would suggest that further experiments should be tried in other parts of India with Indian materials like Road Tar or Digboi Asphalt. As in every phase of human activity the last word is yet to be said, there is a vast field for research on the lines indicated in the paper. It is heartening to note that some work has already been done in the Punjab, Sind and Burma.

*By "Stable" and "Unstable Moorum" is meant such moorum with which the treated surface has remained stable and unstable respectively.

No Census of traffic on this road has ever been taken. The nature of traffic, however, is mixed, having both fast-moving motor vehicles with pneumatic tyres and slow-moving bullock carts with steel tyres In the busy season, the number of bullock carts plying on the road, would not be less than 200, on the average, per day.

The bullock carts in this district usually have $1\frac{1}{2}''$ to $2''$ wide steel tyres fitted on wooden rims of imperfectly circular shape. These wabble over the road and cut the road surface and create havoc. Some carts, though they are very few in number, have disc-shaped wooden wheels without the steel tyre. These are not as vicious as the steel-tyred wheels

The author considers that the failure of the treated surfaces mentioned above, is entirely due to the cutting action of these narrow steel tyres and feels the necessity of an intense drive for the eradication or amelioration of the "vicious circle", either by prohibition as has been done in Jamnagar State or by replacing the steel tyre by wide wooden felloes, or by compromise-tyres such as those foreshadowed in paper No. E-40 of the Proceedings, Indian Roads Congress, Volume VII, Part I.

Such research work and experiments to improve the road surface and to obtain a rational Cart Wheel as cheaply as possible, need all the encouragement from an authoritative body like the Indian Roads Congress, as in the author's opinion the cost of such experiments may result in the ultimate saving of lakhs of rupees in the improvement of India's secondary roads, such as are usually maintained by the District Boards.

The author was originally handicapped in his works for want of facilities for testing soils, but his difficulties were overcome by the timely assistance of Mr Das Gupta of the Standard Vacuum Oil Company, who rendered all possible help in the different stages of the experiments

The author would like to record here his best thanks to Mr Das Gupta, Mr. S K Ghose, Assistant Engineer, Public Works Department, Chaibassa, and also to the Chairman and Vice-Chairman of the Singhbhum District Board for their encouragement and assistance without which it would not have been possible either to carry out the experiments or to write out this paper.

APPENDIX I.

Cost of metalling a road with stone.

For 1 mile long and 10 feet wide road.

Items	Quantity	Rate Rs.	per	Cost Rs.
1. Collection of quartzite stone metal of I. R. C. specification passing through 2½″ mesh screen and retained on 1½″ mesh screen with 1 mile extra lead ..	27,720 c. ft.	7/10	%	2114/-
2. Collection of hard edging and soling stones, with 1 mile extra lead ..	29,333 c. ft.	5/-	%	1467/-
3. Collection of moorum for blinding on top of consolidation..	4,400 c. ft.	1/8	%	66/-
4. Earth work in box cutting for laying and edging stones ..	29,333 c. ft.	5/4	‰	154/-
5. Labour for laying, soling and edging stones and thoroughly packing them .	29,333 c. ft.	-/12/-	%	220/-
6. Spreading, dressing and consolidating stone metal with Steam Road Roller ..	27,720 c. ft.	3/9/-	%	988/-
7. Carriage of Steam Road Roller to work site and back to nearest Railway Station—average distance 15 miles ..	30 miles	1/-	mile	30/-
8. Transport of Steam Road Roller by rail—Chaibassa to Haludpukhur and back .	L. S.			200/-
9. Putting road barrier, caution sign and making diversion road ..	L. S.			25/-
10. Maintaining temporary diversion road for 1 month ..	L. S.			50/-
11. Extra for carriage of water where water is not available within 1 furlong . ..	1 mile	24/-	mile	24/
12. Extra labour for super-elevating curves ..	3 Nos.	2/-	each	6/-
			Total .	Rs. 5344/-

Area of surface metalled $= 10' \times 5280'$

$\therefore$ Cost of stone metalling per 100 sq. ft. $= \dfrac{5344 \times 100}{5280 \times 10} =$ Rs. 10·21/-

APPENDIX II.

Cost of seal coating a metalled surface.

For a surface 5280 feet long and 10 feet wide.

	Items	Quantity	Rate Rs.	Per	Cost Rs
1	Road Tar No. 1 @ 35 lbs per 100 sq. ft. ..	8.25 tons	100/-	Ton	825/-
2.	Road Tar No. 2 @ 32 lbs per 100 sq. ft. .	7.54 Tons	100/-	Ton	754/-
3	Collection of ½" to ¼" quartzite stone chips with extra lead 1 mile ..	2,640 c. ft.	14/2	%	373/-
4.	Collection of sand with extra lead 3 miles ..	1,584 c. ft	6/14	%	109/-
5	Applying Priming Coat of Road Tar No 1 and blinding the same with sand including all costs ..	52,800 sq. ft.	-/3/-	%	99/
6	Applying Second Coat of Road Tar No. 2, blinding the same with stone chips and rolling including all costs ..	52,800 sq. ft.	-/3/-	%	99/-
7.	Carriage of Steam Road Roller average distance 15 miles and back ..	30 miles	1/-	mile	30/
8	Carriage of Empty Tar drums to Railway Station and freight to Lodna Siding ..	L S.			30/-
9.	Putting up barriers, diversions, etc. ..	L. S			25/-
		Total Cost		Rs.	2,344/-

$$\therefore \text{Cost per 100 sq. ft. of seal coating} = \frac{2344 \times 100}{5280 \times 10}$$

$$= \text{Rs } 4.43$$

APPENDIX III

Cost of Surfacing a road with 6 inches of moorum.

For 1 mile length and 10 feet width.

	Items	Quantity	Rate Rs.	Per	Cost Rs.
1	Collection of moorum with a lead of 1 mile ..	26,400 c. ft.	2/-	%	528
2	Spreading, dressing and consolidating moorum with hand roller ..	26,400 c. ft.	-/10/-	%	165
3.	Carriage of Hand Roller to work site and back to Godown–average distance–8 miles ..	16 miles	1/-	mile	16
4.	Putting up road barrier, Caution Sign and making diversion ..		L. S.		40
5.	Maintaining diversion ..		L. S.		40
			Total	.. Rs.	774/-

. Cost of surfacing 100 sq. ft. with 6 inches of moorum $= \dfrac{774 \times 100}{5280 \times 10}$

$= $ Rs. 1.46

APPENDIX IV.

Sheet 1

Cost of treating moorum road with Asphalt.

(a) *Two Coat Painting—*

Surface treated — 230′×10′=2,300 Sq. ft

	Items	Quantity	Rate Rs.	per	Cost Rs.
1	Socofix Primer including freight and carriage to site .	·36 Ton	176/-	Ton	63/-
2.	Socony Emulsion No 3 including freight and carriage to site .	·30 Ton	176/-	Ton	53/-
3.	Liquid Asphalt No. 2 for premix in grooves .	06 Ton	176/-	Ton	11/-
4.	Moorum (washed) ..	92 c. ft.	5/-	%	5/-
5.	Sand average lead 4 miles	46 c. ft.	6/14	%	3/-
6.	Labour for cutting grooves at the edges, cleaning, painting with Asphalt and filling them with premix and ramming the same ..	460 R. ft.	-/10/-	%	3/-
7.	Labour for cleaning the road surface properly and painting the same with 2 coats of asphalt and blinding the same with washed moorum and sand .	2,300 sq. ft.	-/4/-	%	6/-
				Total ..	Rs. 144/-

$\therefore$ Cost of painting 100 square feet $= \frac{144 \times 100}{2300}$

$= \text{Rs. } 6{\cdot}22/\text{-}$

APPENDIX IV.

Sheet 2.

Cost of treating moorum surface with Asphalt.

(b) *1" Premix Carpet.*
Surface treated — 348′ × 10′ = 3,480 sq ft.

	Items		Quantity	Rate Rs.	Per	Cost Rs
1	Socofix primer	..	14 Ton	176/-	Ton	25
2	Socofix	..	77 Ton	176/-	Ton	136
3.	Socony Emulsion	..	15 Ton	176/-	Ton	26
4.	Washed moorum	..	329 c. ft.	5/-	%	16
5	Sand average lead 4 miles	..	113 c ft	6/14	%	8
6.	Labour for cutting grooves at the edges, cleaning, painting with asphalt and filling them with premix and ramming the same	..	696 sq. ft.	-/10/-	%	
7.	Labour for cleaning the road surface properly and painting the same at edges, making premix and laying the same on the surface and rolling	...	3,480 sq. ft.	-/13/6	%	29
				Total Cost	..	244/-

Cost of 1″ Premix Carpet per 100 sq. feet $= \frac{244 \times 100}{3480}$

= Rs. 7·01/-

Wednesday, 6th October 1943.

Mr. N. V. Modak (Chairman) called upon Mr. A. K. Gupta to introduce his paper.

Rai Sahib S. K. Ghose introduced the above paper on behalf of Mr. A.K. Gupta who was unavoidably absent.

Discussions.

Mr. C. I. Zaman (Assam) :—The author of this paper deserves congratulations for the experiments he has been able to carry out and bring before the Congress, despite the difficulties under which he had to work with the handicap of finance.

Moorum—as I find from the words of the author—is a soft stuff, consisting of sand and clay. This quality itself debars the material from being used with any surface dressing. The success of all surface dressings, as we know, depends upon the hardness of the road metal used, and also of the chippings used. I am not surprised, therefore, to find from the paper itself, that the surface treated portions of the experiment have failed and broken up within such a short time. The author seems to attribute this failure to narrow cart wheels. I think the poor bullock cart wheel is not the right offender in this case.

The author admits that no traffic census was taken on the portion of the road under experiment—neither before nor during the experiment. An experiment of this type certainly loses its value—unless such useful data are collected The author seems to have aimed at making a low cost road. In my opinion, as road engineers, our aim should not be the making of low cost roads only but the building of the right kind of road for the appropriate kind of traffic at the minimum cost.

I want to bring to your notice another aspect of the experiment. The author in page 65 states.—

"In lengths where two coat painting was done, rain-water collected near the edges due to bad drainage, and crept under the painted surface and softened the base. At these places, the cutting action of the steel-tyred bullock-cart wheels severed pieces of the hard crust of bitumen and moorum, from the main body and made pot holes.

This is a very important factor which engages the attention of all Road Engineers specially in places where rainfall is heavy. Subgrade drainage is one of the fundamental requirements of road making and, I think, the author's remedy of providing 4 ins. deep premix strips is too inadequate to prevent water creeping in and softening the subgrade..

Mr. A. S. Adke (Bombay) :—I congratulate Mr. K. Gupta for carrying out experiments on moorum roads in his District with a view to stabilize the surface with asphalt painting and asphalt carpeting and presenting his results in detail to the Indian Roads Congress. It is really

an ambitious scheme as far as village roads are concerned If his experiments prove successful, I think the villagers will be quite happy.

The author of the paper has avoided the question of finance altogether. When we are considering the question of improving our road surface on a large scale, I think the question of finance cannot be kept in the background. The author of this paper had to thank his Chairman for getting him Rs. 2,500/- for carrying these experiments, but if Mr. Gupta means to carry out his experiments of carpeting on a larger scale, say on a length of about 10 miles of road, I do not think the budget of the District Board will allow him to do so. Such problems are very distant to the Boards I, however, like to make some observations on the experiments of Mr. Gupta.

Please refer to the Page 69 wherein the author has given the cost of metalling the roads with stone. He has provided 6½ ins. of thickness of metal for 10 feet road This is rather too thick for a District road and I think that 3 ins. coating of metal is more than sufficient for such type of road. Again the author has included the cost of materials for soling as Rs. 1,467/-. Presumably the subgrade must have been soft one The same cost of soling would have been required for moorum surfacing if moorum road was proposed here Also Rs 230/ is included for transport of steam road roller. It should not have been included in this item of road consolidation, as this does not form part of the work and will be comparatively much less if greater length was taken for working If these items are omitted and if 3 ins. coating is provided the cost, as per rates given by the author, will be Rs. 4/8/- per 100 sq. ft. and not Rs. 10.21. If the cost of soling is taken into account the figure may rise to Rs. 7·5 per 100 sq. ft. The cost of sub-grade will be common whether you take up moorum surfacing or metal surfacing and whether you further develop it by asphalt painting or carpeting. So when you compare such figures, similar circumstances should be taken, as far as possible So far as my experience goes, this type of surface of 3 ins. of metal thickness will last for 3 years for normal traffic and if you put another coat of metal of 1½ ins. thickness, I believe the life of the road will further extend by a period of another 3 years. This cost of renewing the surface will decidedly be less

In place of metal coating, Mr Gupta proposes moorum coating with further asphalt painting or carpeting. As the author has himself admitted that asphalt painting has proved a failure due to grinding and cutting action of bullock cart iron tyres, I need not discuss this point. He has, however, said that carpeting with asphalt and moorum has stood well. The cost of this including moorum surfacing comes to Rs 5 99 per 100 sq. ft I feel that this surface has stood well due to [1] hard sub-grade, [2] good quality of moorum and [3] adequate thickness of the asphalt carpet. It has been often complained that asphalt carpeting does not stand well where the cart traffic is heavy even though the carpeting has been done on old macadam surface Due to cutting action of the iron tyred bullock cart, the surface of the carpeting is cut As this carpet is standing on moorum surfacing, this action is bound to be accelerated If this experiment is performed on a road surface where the embankment is high and the sub-grade is not quite hard, I fear the carpet will not stand long. The embankment is bound to settle down due to traffic impact and

once the surface of the carpeting is disturbed, the whole carpet will be torn to pieces. Even otherwise if once the ruts are formed, the storm water is bound to get into embankment and the whole of the surface is bound to be disturbed. It is therefore no use taking up such schemes, unless you are sure of maintaining the same. Mr. Gupta might have been able to get sanction for Rs. 2,500/- for his experiments by his District Board, but I am doubtful whether he will get further funds for the prompt repairs of such road surface. If he does not get funds to keep such road surface in tact, the surface is bound to be cut by ruts and then after 2 or 3 years, it will be difficult to say whether it is an asphalt road or a moorum road. The moorum has got the great advantage that it can be repaired any time.

A dust-proof asphalt road, will certainly improve, the general health of the public. But the cost of construction and maintenance of the road, the moorum or metal road depending upon the type of traffic, will decidedly be cheaper. The cost of 3 ins. metal road will be Rs. 4.8 per 100 sq ft. exclusive of the cost of soling. In case of asphalt carpeting the cost will be Rs. 5.99, the life in both the cases being 3 years only. The further cost of renewing the surface after this period will also not be favourable to the coat of carpeting. It is therefore no use to think of such ambitious schemes by the Rural Engineers unless our finances are considerably improved. Till then we have to remain satisfied with our dusty roads. If we can carry on the rural traffic of bullock carts and head loads with least possible resistance of road surface, we must thank ourselves. I, therefore, think that a hard moorum or metalled surface provided with dips or culverts will be the best line of communication for the rural area till Government comes forth to their aid by giving liberal grants for improvement in the road surface or the financial position of the Boards is improved by compulsorily raising the taxation and earmarking the money thus devised for road improvement.

Mr. J. T. Mehta [Bhavnagar].

I find the paper very interesting as I am myself faced with the problem of evolving something to maintain moorum roads cheaply. I congratulate the author for his enthusiasm and spirit. However, I would like to make a few comments. The spirit in which they are made is one of constructive criticism and I request they be not misconstrued.

The experiments seem to have been carried out on a line which is a negation of fundamentals. In the structure of a road, the subgrade, the foundations or base, and the wearing course, all have their functions. It has been shown by various authors at previous sessions that, in order to withstand the grinding action of narrow iron tyres which may even be wobbling, the quality of grit used in surface dressings should be sound and it must have affinity for bitumen. What forms grit in this case? Merely moorum which is the product of disintegration of weathered rocks. I do not know how we can suppose that this will stand.

If this cart weighs $1\frac{1}{2}$ tons, it will require a crust of at least 5 inches for a very good gravelly subgrade, to sustain this load; (vide the graph from the paper submitted by Mr. Jagdish Prasad and Sir Kenneth Mitchell at the 4th Indian Roads Congress). If this crust be provided, it will be a help to drainage also, as the percolating moisture will be less, and the subgrade will be affected to a lesser degree by it.

In the experiments carried out, a treatment has been given to Moorum subgrade, costing Rs 7.01 per 100 sq ft, whereas it is shown in appendix I that a metalled road would cost Rs. 10.21 per 100 sq. ft. I am sorry to say that it is misleading, because in the cost of metalling is included 7 inches of rubble soling and 6¼ inches of metalling If the subgrade is assumed to be good enough to carry the wheel loads directly, why a 12 inches crust is taken for comparison? As I have said, a 5 inches crust would be required and this would cost in the region of Rs 5 per 100 sq. ft

If the motor traffic on this road be less than 200 vehicles per day, this metalled crust, untreated, would have an economic life of about 3 years It is unfortunate however that traffic count has not been taken before proceeding with the experiments. The author says that the maximum number of bullock carts in the busy season would be 200 per day, hence if the motor traffic be more than mentioned above, a single coat or two coats painting on the crust would stand the same for 3 to 4 years

Some specifications with leaner soling coat have been tried in the Punjab for strategic roads with success, as mentioned in paper I 1943. It would be better if the author tries something on that line, or else, stabilization of moorum subgrades may be tried. Surface treatments are not useful for stabilization. A thickness of about 4 ins. will have to be treated Gravel or bitumen or both may be tried, but, drainage must receive first attention For compaction, a sheeps-foot roller should be used in the initial stages.

Rai Sahib S.K. Ghose [Bihar].

It is but natural that at the outset the present critic should avail of this opportunity to reciprocate the kind feelings expressed by Mr. K. Gupta at the end of his excellent paper, which faithfully portrays the condition of the moorum roads in Chota Nagpur. One need not come all the way to Chota Nagpur to verify the observations made in para. 2 of the paper, it is unfortunately true for most of the roads in India, a sad reflection on the engineers' helplessness in trying to provide dust-free, mud-free, bump-free roads for all, while the creaking cart-wheels crush his best roads out of shape! Perhaps the writer may be pardoned for quoting in this connection from an article of his in the 'Modern Review,' July 1940, "There are more than 100,000 miles of so-called motorable main roads in India, out of which 90 per cent have bumpy, dusty tracks, disseminating filth and disease in the dust clouds raised by the passing vehicles, which destroy and in turn are destroyed by the bad road surfaces, and the vicious circle entwines India in its octopus-like tentacles even today when so many other lesser countries have forged ahead rapidly in the matter of road development".

Thanks to the war, the method tried by Mr. Gupta on the gravel road from Jamshedpur to Ghatsila cannot be tried even on paper now, as neither Bitumen nor paper is available for such purposes. The author has been modest enough to give the names of the two nearest villages, at the ends of his experimental section, but it is perhaps desirable that members should note that this important road which connects the

premier Steel City to the only Copper City of India is still in the "gravel" age of stage development. Looking to the traffic being carried on this busy road, even a layman would have thought that it needed a regular metalled and sealed road surface. But the District Engineer was confronted with the unenviable task of performing miracles with gravel only.

He very nearly succeeded in establishing a more economical road surface; but, the steel-tyred cart wheels surely and relentlessly searched for the weak spots below the "sealed" armour, and ultimately tore big holes in the road-way. The foundation could not stand the screwing and wrenching action of the wobbly steel tyres of the carts carrying heavy timber from the Kalikapur forests.

It is a pity that the Author left Singhbhum shortly after the completion of the experiments, as he could have followed these correctly to their logical conclusion. It has, however, been definitely proved now that such surface treatments cannot stand up to heavy cart traffic.

Table V. [Page 67] is interesting as it indicates that moorum containing less than 50 percent of coarse aggregate (quartz) is unstable under load. Under field conditions, it is difficult to consolidate the moorum at *Proctor's Optimum moisture content*, and it has been a satisfactory rule evolved by the present writer who has to maintain about 150 miles of gravelled roads never to allow more than 1½ inches of moorum (loose thickness) to be rammed along the two running tracks in longitudinal strips, for patch repairs where the moorum has worn thin, minimum water being added to allow proper tamping.

For the benefit of the "curiouser" readers, certain "standard" data* not given by the author in the paper are noted below:—

III. (a) Height of embankment above ground level 1ft. to 1ft. 6ins. above adjacent rice fields.

(b) Normal H. F. L.—Area not liable to floods.

(c) Ht. above M. S. L. 550 to 600 feet.

V. Nature and material and condition of old road including subgrade and soling—

Over old consolidated moorum surface, but with practically no soling anywhere. The sub-grade was fairly stable stony soil over Newer Dolerit area.

VI. Temperature in degrees Fahr.	Max.	Min.
(1) During construction	104	79
(2) Range during year	Not known.	

VII. Rainfall :

(1) During construction—5.9 inches.

(2) Yearly average— 57.38 "

Mr. Gupta is to be congratulated on this very interesting paper.

*Pages 62 to 64.

PAPER No. E-41.

FURTHER DEVELOPMENTS IN VILLAGE CEMENTS AND HIGH SILICA PORTLAND CEMENTS FOR THE CONSTRUCTION OF CONCRETE ROADS

BY

MR A K DATTA, B.E., C.E., M.I.E. (IND.), M A.E.,

Consulting Engineer & Master Builder, Calcutta.

This paper is in continuation of author's paper No. C/39* of 1939 for "Development & Application of Village cement and High Silica portland cement for the construction of Concrete Roads".

Experiments on High Silica portland cement had shown that the maximum strength of tensile briquettes was obtained by mixing 65 to 75 per cent cement with 35 to 25 per cent Jhama or Artificial Puzzolana In the experiments made previously by the author, he found the maximum strength by mixing 65 per cent cement with 35 per cent jhama or artificial puzzolana This maximum strength is now obtained with 70/30 mix.

Referring to experimental results of new experiments in Sheet 2 on the increase in strength by the addition of jhama, we find that the maximum strength was produced by adding 70 per cent cement and 30 per cent jhama.

Some experiments on High Silica portland cement were conducted by Mr. C.A R Khan & Mr. Lal C Varman of the Research Department, Government Test House, Alipore, as published in the "INDIAN AND EASTERN ENGINEERS" June 1940—pages 613-615, which showed results similar to the above Maximum results were obtained in some cases by adding 70 per cent cement with 30 per cent over-burnt surkhi or jhama. (See Appendix I—pp 84-85)

From these illustrations it is seen that the maximum strength for the High Silica cement is got by mixing 65 to 75 per cent cement with 35 to 25 per cent jhama or artificial puzzolana.

From the analysis of High Silica cement of 65/35 mixture, we find—

CaO	.. ..	42.6 per cent
SiO_2 & insoluble residue		44 24 ,,
Al_2O_3	.. ..	5 72 ,,
Fe_2O_3	.. ..	2.3 ,,
MgO	.. ..	2.99 ,,
SO_3	.. ..	1.43 ,,
Loss in ignition	.. .. ..	1.55 ,,
		100.83

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*Sixth Proceedings of the Indian Roads Congress, 1939.

Vicat, *the famous French Chemist*, considered that for obtaining resistant cement, the composition should be such that—

$$\frac{SiO_2 + Al_2O_3}{CaO + MgO} > 1$$

Here we get $\frac{44 \cdot 24 + 5 \cdot 72}{42 \cdot 6 + 2 \cdot 99}$ or $1 \cdot 1$.

As this value is greater than 1, the mixture complies with the condition laid down for resistant cement by M Vicat.

According to *Dr. Michaelis of Berlin*, the present portland cement is not all-round the best of all cements. It requires further improvements.

Dr Michaelis (*vide Portland cement by Butler* page 375) strongly disagreed with the sweeping assertion of the Members of the German Association of cement manufacturers that all additions of a foreign material weakened portland cement, and he brought forward the researches in support of his contentions that some substances, viz, those containing hydraulic silica etc might be advantageously mixed up with cement.

In page 332 of Vol CXXIX of the Proceedings of the Institute of Civil Engineers, we find the following:—

"The addition of Trass or artificial puzzolana to hydraulic cement containing an excess of lime, such as portland cement, can increase the strength of mortars twice or three times and render them stable in sea water This is not surprising as the best puzzolanas contain as much active hydraulic material as the best portland cements"

"Hydraulic cements which contain more lime than is required to form stable hydro-silicates and hydro-alluminates, should not be used for marine work unless improved by addition of substances such as those named."

A comparison of typical analyses of portland cement, High Silica cement, river mud, inland mud & puzzolanic material (*Vide* a Handbook for Cement works—Chemistry by Frank B Gate House—page 158)

	Typical composition of portland cement Per cent	Analysis 65/35 mix of High Silica cement Per cent	Typical analysis of river mud, dried at 105°C Per cent	Typical analysis of clay in land Per cent	Typical analysis of puzzolanic material Per cent
CaO	63 48	42 6	1·96	1 55	10 48
SiO_2 (Sol Silica)	21 07	44 24	26 85	26 86	44 91
Insoluble sand etc	—	—	30 29	39 75	X
Al_2O_2	7 00	5 72	16 68	13 96	17 92
Fe_2O_3	2 61	2 3	6 60	6 58	8 40
MgO	1 34	2·99	2 14	1·59	4·81
SO_3	2 23	1·43	—	0 27	—
Loss in ignition	1·35	1 55	11 94	7 99	7 76
Sulphur as sulphide	—	—	—	0 06	
Alkalies & loss	—	—	3 54	—	4 89
	99 99	100·83	100·00	98·61	100 00

In page 375 *of "Portland cement" by Butler* we find "Of all known additions to this kind, the most effective is real *Trass* on account of the high proportion it contains of the hydraulic factors and of the excellent quality of that portion of it, which acts as sand."

In puzzolanic material as Trass etc, we find the percentage of lime (CaO) as about 10, whereas, in case of clay it is not even 2. From analysis of jhama bricks, it is seen that the silica (SiO_2) is partly soluble and partly insoluble. The soluble part of the silica reacts with lime easily, whereas insoluble silica acts as sand In case of *Trass* (puzzolanic material) the whole of the silica is practically soluble like that in cement That is the reason why *Trass* when mixed with lime or cement gave better results than artificial puzzolanas, similarly treated.

Puzzolanic cement once used by Romans consisted sometimes of volcanic *Tufas*, which were of a porous open grain structure (note here there is a similarity with porous jhama) mixed with slaked lime and those produced a durable cement, used by ancients for building construction.

Again, referring *to page 31 of the same book "Portland cement" by Butler*, we find "The puzzolanic materials alone do not produce a cement. The presence of a cementing addition is a necessity, while the activity of the ground volcanic material depends on the presence of soluble silica or Hydro-silicic acid which readily enters into combination with lime hydrate."

Again, referring to page 10 of the same book we see—"*Though successful in some cases it was notorious that in the majority of instances where the artificial puzzolanas had been used on a large* scale, failure had followed."

M. Vicat closely examined the causes of these failures and concluded that the hydrochloride of magnesia of sea water penetrated the imperfectly carbonated portion of the cement and led to the disintegration. He was thus led to believe that puzzolanas produced by volcanic heat differed from those produced artificially and the inference would be that to create a perfect cement, it was necessary to mix the clay with carbonate before calcination.

Again, referring to page 251 of "The Chemistry of cement and concrete" by Lea & Desch, we find as follows :—

"A puzzolanic cement composed of heat-treated volcanic ash, free from alkalies, mixed with 20 per cent by weight of lime and 5 per cent gypsum is manufactured in Italy. Puzzolana used of approximate composition—

SiO_2	..	46 per cent
Fe_2O_3	..	11 „ „
Al_2O_3	..	22 „ „
CaO	..	10 „ „
Loss in ignition	..	10 „ „
		99 per cent

"It is claimed that this cement sets or hardens more rapidly than ordinary mixes of lime and puzzolanas and has a specially high resistance

to attack by sea water The gypsum, the presence of which it is claimed accelerates the set, is stated to form Lafuma's Calcium-sulpho-silico-aluminates by reaction with the puzzolanas The heat treatment of the puzzolana increases the proportion of soluble silica and alumina. The same type of puzzolana is also used in the production of puzzolanic portland cement. Two Trass portland cements, premixed and packed in bags, containing respectively 30 and 50 per cent Trass, are now also marketed in Germany.

On burning clay to jhama, a good part of the silica and alumina of clay is reduced to soluble silica and alumina but even after that a large part of the silica remains as an insoluble sand Now if we add some lime or limestone powder with the clay and thoroughly mix up the same, from the mixed stuff we make the bricks or lumps and burn the same in ordinary brick or lime kilns with a little excess coal we shall easily get jhama bricks or lumps in plenty and in these jhama bricks or lumps we shall get most of the silica and alumina as soluble and will thus be far more active than ordinary jhama where the percentage of soluble silica and alumina is limited. It is for this limited amount of soluble silica and alumina in artificial puzzolana, some cases were successful while others were failures in the case of Experiments by M Vicat So this new method of manufacture of jhama bricks or lumps will make these artificial puzzolanas much more active than even natural puzzolanas.

Thus that will be a great development in the manufacture of High Silica portland cement.

It will be within the easy reach of these brick kilns and lime kilns to turn out easily these activated jhamas or lumps and we can grind these to cement specification and mix up in proper proportion with portland cement to produce the High Silica portland cement If cement clinkers are added, necessary quantity of gypsum is to be added also The proportion of cement and activated jhama will be dependent on the lime content in the jhama. It can be 2/3rd & 1/3rd, half and half, or 1/3rd and 2/3rd, or similar other proportions.

Thus the Village cement manufacture on the above lines has immense possibilities in the future. The quality and strength of the Village cement will both improve and that cement can be reliably used in the construction of the Concrete roads

Every country has her Silica cement :—

Germany	—	Trass cement	—	70/30 and 50/50	mix
France	—	Gaize cement	—	75/25	mix
Italy	—	Puzzolana blended portland cement	—	75/25	mix
Denmark	—	Moler cement	—	75/25	mix.
England	—	Potter's Red cement	—	75/25	mix.
Japan (Osaka)	—	Silica cement	—	75/25	mix. and
			—	65/35	mix
India	—	Datta's Silica cement	—	70/30	mix. and
		or Jhama cement		50/50	mix

Referring to page 656 "Encyclopædia Britannica" under heading "CEMENT", we find that ordinary portland cement contains mostly Tri-Calcium silicate, which when hydrated with water, liberates free slaked lime

$$2(3\ CaO.\ SiO_2)\ \text{plus}\ 9\ H_2O = 2(CaO.\ SiO_2).\ 5\ H_2O\ \text{plus}\ 4\ Ca\ (OH)_2\ \text{(slaked lime)}$$

$$3.CaO.\ Al_2O_3\ \text{plus}\ 12\ H_2O = 3.\ CaO\ Al_2O_3.\ 12H_2O.$$

It will be observed that in the hydration of Tri-Calcium silicate,—the main constituent of portland cement—, a large proportion of lime appears as Calcium Hydroxide i e Slaked lime.

It is evident therefore that this will form a puzzolanic cement if a suitable silicious material, such as Trass is added to the cement The ultimate product when set may be regarded as a mixed portland and puzzolanic cement

Free slaked lime in the present portland cement, when set, is a source of weakness. In order to produce a stabilised cement, containing only the stable compounds, we shall have to manufacture standard portland cement, rich in lime and another activated lime clay clinker or jhama, rich in active silica and alumina; on combining two together in proper proportions, we shall get a stabilised cement, where the free lime of the former will be compensated by the active silica and alumina of the latter. When the exact proportions are found it will not be difficult to fix up the standard for High Silica portland cement, to protect the same from adulteration. Even then, only the high standard of strength with age much above the portland cement will protect it from adulteration. (See Appendix II, p. 85.)

Thus in order to have stabilised portland cement we shall have to manufacture two kinds of clinker, one of the standard portland cement and the other of activated jhama clinker, with lower lime content and the higher silica and alumina content and the two kinds of clinkers are to be so mixed that the free lime liberated from the standard portland cement may combine with the active silica and alumina of the activated jhama clinker. The manufacture of activated jhama clinker can easily be done in ordinary brick or lime kilns as the percentage of lime added to the brick earth is not high enough to prevent it from being fused in ordinary kilns. This activated jhama clinker can be ground with portland cement available nearly everywhere. So it will be possible to manufacture high class cement in village areas. In the case of Cement Factories two kinds of clinkers could be manufactured and from the same, High Silica portland cement could be easily manufactured That will be useful for the factories from another consideration also, that lime-stones with lower lime contents will be profitably utilised by this process. We can therefore hope that by this process, the cost of High Silica cements will be much lowered to be economical for the construction of Concrete roads.

It will not be out of the place here to compare the High Silica portland cement and Village cement with the blast furnace slag cements which are now very commonly used in Europe and study of which had been very thorough also.

Blast furnace slag cements are the least costly of all cements

Referring to the pamphlet on cement from blast furnace slag by G. Polysius of Dessau, Germany, manufacturers of Cement Machineries we find in page 9,—

Slags from Blast furnace, suitable for the manufacture of cement by grinding

	Highly reactive	Slowly reactive
SiO_2	27—31 per cent	33—37 per cent
Al_2O_3	13—20 „	10—12 „
CaO	50—45 „	50—40 „
CaS	8— 4 „	4— 2 „
MgO	8— 2 „	3— 1 „

Blast furnace slag, suitable for making cement by grinding the lower limit of CaO = 42%.

The most valuable slags unite a high percentage of lime with a high percentage of alumina, the proportion of silicic acid ought to be limited.

By grinding the slags the following cements are manufactured:—

(1) Slag Cement	75 per cent	blast furnace slag.
	25 „	hydrate of lime

The slag should contain.—50 to 40 per cent of lime.

27 to 37	„	silica.
10 to 20	„	alumina
2 to 8	„	Calcium sulphide.
1 to 8	„	Mag Oxide.

(2) Iron portland cement.—	30 per cent	Blast furnace slag.
	70 „	portland cement clinker
(3) Blast furnace cement —	70 „	Blast furnace slag.
	30 „	portland cement clinker.

It will be seen that the slag cement is quite different from the rest. The methods of production in this case consist in the simple burning of the lime and a further favourable circumstance is that the consumption of raw materials is reduced by hydration with water For the rest the blast furnace cement appears to be most advantageous Experience has proven that cements from blast furnace slags must be more finely ground than ordinary portland cements

From these figures we can easily see that in making our activated jhama clinkers it will be better to have 40 to 50 per cent of lime, 27—37 per cent silica, 10 to 20 per cent alumina. The higher the percentage of lime and alumina is, the better will be the quality of activated jhama clinkers. Rapid cooling will be necessary and that can be arranged easily in case of brick kilns by removing the covering rubbish on the bricks

(A) We can make cement similar to slag cement by mixing:—

Activated jhama clinker—75 per cent
Hydrate of lime 25 per cent

(B) We can make cement similar to Iron portland cement by mixing:—

Activated jhama clinker — 30 per cent
Portland cement clinker or portland cement } 70 per cent

(C) We can make cement similar to Blast furnace cement by mixing:—

Activated jhama clinker — 70 per cent
Portland cement clinker or portland cement } 30 per cent

(See Appendix III, pp. 86—89.)

NEW EXPERIMENTS

Elaborate experimental researches on Village cement and High Silica portland cements were undertaken by the author from August 1941 in Dalmia-Dadri Cement Laboratory (Jind State) and in Dalmianagar Cement Laboratory (Bihar) The results have been given in the enclosed Charts in Sheets Nos. 1 and 2, pages 91-92.

Experiments 1 to 28 are on Village cements and 29 to 43 are on High Silica portland cements. In all these experiments, samples were made first All materials were ground finely to cement specification in Laboratory Ball Mill at Dalmia-Dadri Cement Factory and they were mixed separately The mixing was done in the Ball Mill again for 15 to 20 minutes, so as to ensure thorough mixing of the ingredients. All physical tests, on samples viz., fineness, setting time, soundness, tensile strength with sand (1·3) at 3, 7, 28 and 90 days, were made in Dalmia-Dadri Laboratory.

A part of each sample was taken to the Chemical Laboratory, Dalmianagar (Bihar) and tested with 3 times the weight of sand (1 3) to find the corroboration of the tests of Dalmia-Dadri Laboratory. The object of making tests in two different Laboratories is to be certain about the results of tests. The samples were gauged in Dalmianagar Laboratory about 3 weeks after the gauging at Dalmia-Dadri; so the results of Dalmianagar Laboratory came out somewhat lower than the others. Sone sand of the standard gauge was used in all these tests in both laboratories. The author is thankful to the Laboratory Authorities, Chemists and their assistants for the help in conducting these tests.

The results have been tabulated under the heading :—

"Experimental Researches on Artificial Puzzolanic cements".

Experiments were undertaken under 10 different Groups.

(I) *Group A*—Lime, jhama, gypsum—Experiments 1 to 7. Of these Experiments 1-6 are with lime and jhama in different proportions,

as 1:1, 1 2, 1.3, 1:4, 1½.1, 2.1 with 5 per cent gypsum and Expt 7 is with 1½:1 with 10 per cent gypsum—to find the effect of excess of gypsum. These results are extremely interesting. In Experiments No 3 and 4, we find the strength of 1 3 mortar higher than portland cement (1·3) mortar (Expt No 29) in 90 days The results are 695 lbs 624 lbs per sq. in. as compared to 585 lbs. per sq. in. Experiment 7 as compared to Experiment 5 showed that the tensile strength was not increased by adding excess amount of gypsum

(II) *Group B*—Lime and jhama—here no gypsum was added to see the effect of gypsum on the strength of mortars Experiments 8, 9, 10 are with 1 1, 1 2 and 1·4. The results at 90 days are much lower than Group A, with gypsum

(III) *Group C*—Lime, jhama and burnt gypsum. In Experiments 11, 12, and 13, 5 per cent burnt gypsum had been added. Here we do not find higher strength than with ordinary gypsum. By adding gypsum, the setting time was accelerated So there is no advantage in adding burnt gypsum in the place of ordinary gypsum It is to be noted also that the fineness in Group A was better than Group C.

(IV) *Group D*—Lime, jhama, gypsum and ordinary cement Experiments 14, 15, 16. Lime, jhama, burnt gypsum and cement. Experiment 16A. In experiments 14, 15, and 16, cement 20 per cent by weight of lime and jhama had been added with 5 per cent gypsum. In spite of the addition of burnt gypsum, the results are not higher than those in Group A This is interesting Experiment 16A shows that the setting time is accelerated by the addition of burnt gypsum but not the strength. *So there is no use in adding burnt gypsum in the place of ordinary gypsum.*

(V) *Group E*—Lime, red soorkhi, gypsum—Experiments 17, 18, 19. As compared to jhama in Group A, these results are comparatively lower. Proportion of 1 4 gave higher strengths than 1 1 and 1·2 With red soorkhi the strength with 1 3 mortar was 466 lbs per sq inch, whereas, with jhama the strength was 629 lbs per sq in (Expt 4) Even lime jhama in Group B is stronger than lime, red soorkhi and gypsum The results are very high as compared to lime soorkhi in Group F

(VI) *Group F.*—Lime, red soorkhi—Experiments 20, 21, 22 It is to be noted that the fineness is low in these experiments The strength would have been somewhat higher if the fineness had been better. The strength of mortar is considerably lower as compared to Group E with gypsum.

(VII) *Group G*—Lime, red soorkhi, burnt gypsum—Experiments 23, 24 and 25 The results are not higher than those in Group E, with lime, red soorkhi and gypsum *So there is no direct advantage by adding burnt gypsum in the place of unburnt gypsum.*

(VIII) *Group H.*—Lime, red soorkhi, gypsum and cement.—Experiments 26 and 27. Lime, red soorkhi, burnt gypsum and cement Experiment 25 These Experiments show that there has been considerable increase in strength, much higher than portland cement, *vide* Experiment 29. In Experiment 27, the strength of 1·3 mortar

in 90 days is 675 lbs. sq. in. as compared to 585 lbs. per sq. inch for portland cement.

In the manufacture of Village cement, Experiment 27 can be followed easily. This has got a great future.

We find best results in Group I and Group VIII and moderately good results in Group II and Group V.

The author wrote to Mr. Syed Arifuddin, Chief Engineer and Secretary, P. W. D., Irrigation, Drainage, Hyderabad State, and a Member of the Council of the Indian Roads Congress, to try some of these experiments. In reply, he wrote he would do and communicate the results to the author. Some of these experiments are being repeated now in Dalmia-Dadri Laboratory.

After conducting these experiments the author feels convinced that there are immense possibilities in the manufacture of cement. We can manufacture cement at a cheap cost which will be stronger than portland cement with age, (say after 3 months), will not contain any free lime like set portland cement and will thus stand better than portland cement with age.

The advantage with portland cement is that it gets strength at a very early age, whereas, our new cement will not be so strong as portland cement at early age but with age will be stronger. This is a thing worth consideration for all Engineers.

(IX) *Group I.*—Experiments on High silica cement, cement jhama, Experiments 29, 30, 31, 32, 33, 34 These results corroborate the results obtained previously as given in Paper C/39.*

70/30 mix (Expt. 32) gave a strength of 713 lbs per sq. in. for 1:3 mortar as compared to 585 lbs. sq. in. for portland cement mortar 1:3 (Expt. 29) in the same period of 90 days. Thus we get confirmation of the tests from experiments done at Dalmianagar Cement Factory Chemical Laboratory; at Government Test House, at Alipore; and also at Dalmia-Dadri Cement Laboratory. We can safely state *that we can produce High Silica cement by adding cement and jhama, where the free lime liberated at the setting of the cement combines with the active silica and alumina of jhama, finally ground to cement specification.*

Experiments 35, 35A, 35B, 35C —Cement, jhama, slaked lime. Here we find the effect of lime on cement jhama mix. Addition of lime made the cement more plastic but reduced the strength at the early age and with age the strength revived.

(X) *Group J.*—Cement, red soorkhi. Experiments 36, 37, 38, 39, 40. Here we do not find the same increase in strength as in Group I, with jhama. Cement, red soorkhi and lime—Experiments 41, 42, 43, 44. In these experiments where the percentage of cement is low, lime has been added to find if the strength increases with age.

*Development and Application of Village cement and High Silica Portland cement for the construction of Concrete Roads by the same author sixth proceedings of the Indian Roads Congress, 1939.

On the whole, these experiments show very clearly the importance of jhama, when ground finely to cement specification, both with lime and with cement. We see clearly now why structures made with Roman cement, 2000 years back, are standing the atmospheric action even under sea water in excellent condition In ancient time, there was no machinery to grind the lime puzzolana to that fineness of cement *i.e.* to pass 170 mesh per inch, but now with the help of Ball Mills we can grind easily cement clinker, jhama and gypsum, or lime, jhama and gypsum to a fineness of cement specification

APPENDIX No. 1

Results of Experiments on "Cement—soorkhi mortars" by C.A R. Khan & Lal C. Varman—published in the "Indian & Eastern Engineers", June 1940—in pages 613-615. These Experiments were conducted at the Government Test House, Alipore, by the Research Department. These results are very interesting and confirm the results obtained by the author as published in his Paper C/39.*

Table I

Effect of over-burnt soorkhi on strength of cement "A"

Composition by weight			Tensile strength in lbs. per sq. in. at—			
Sand	cement	over-burnt soorkhi	3 days.	7 days.	28 days.	3 months.
300	100	0	607	614	668	686
300	95	5	623	693	710	726
300	90	10	656	715	730	737
300	85	15	628	645	773	787
300	80	20	575	636	774	796
300	75	25	565	635	749	842
300	70	30	517	563	721	851
300	65	35	510	545	700	795
300	60	40	480	510	625	625

Table II

Effect of over-burnt surkhi on strength of cement "B"

Composition by weight.			Tensile strength in lbs. per sq. in. at—			
Sand	cement	over-burnt surkhi.		7 days.	28 days.	3 months.
300	100	0		463	502	514
300	95	5		484	521	537
300	90	10		496	523	551
300	85	15		517	598	665
300	80	20		568	633	683
300	75	25		561	618	760
300	70	30		558	610	789
300	65	35		489	583	723
300	60	40		484	578	702

* Proceeding I. R. C., Vol. VI, paper C-39.

From Table I, we find mixes, 100/0, 75/25, 70/30 getting strength

	100/0	75/25	70/30	
in 3 days	—607	565	517	lbs /sq. in.
7 „	—614	635	563	„ „
28 „	—668	749	721	„ „
3 months	—686	842	851	„ „

From Table II, we find the results from the same mixes as follows—

	100/0	75/25	70/30 mixes.	
In 7 days	—463	561	558	lbs /sq in.
28 „	—502	618	610	„ „
3 months	—514	760	789	„ „

These results corroborate the results obtained by the author in his experiments.

That shows that there is good prospect for Silica portland cements, as their final strengths are much higher than those of portland cements and the cost of production will be somewhat lower.

APPENDIX No. II

Portland cement when it sets liberates a lot of free lime. Thus set cement contains a large amount of free lime.

In order to determine the amount of free lime in set cement, the author took a piece of set cement from an old setting lime mould left outside the laboratory at Dalmia-Dadri Cement Factory, and got it analysed in the Chemical Laboratory by Mr T. C Puri, M.Sc, Chief Chemist of the Laboratory. The analysis is as follows:—

Free lime as CaO plus $Ca(OH)_2$ in set cement.

Weight of set cement taken from an old setting lime mould left outside laboratory and several months old—

> Wt of set cement—·5 gramme.
> Boiled with 25 c. c. of Methyl Absolute Alcohol and 5 to 6 c c. of Glycerine with air condenser, a few drops of Phenol-thalin indicator were added to Alcohol.

Titrated hot with standard Amonium Acetate solution till the pink colour disappeared Again it was boiled for about half an hour and when the pink colour appeared it was again titrated hot with Amonium Acetate solution. It was repeated till the pink colour did not reappear after boiling for 1 hour.

(Standardisation of Amonium Acetate solution—Dissolve 16 gms of Amm. Acetate in 1000 c c of Absolute Methyl Alcohol. Take ·1 gm. of freshly prepared CaO, boil it with 25 c c of Alcohol, 5 c.c. of Glycerine, few drops of Phenapthalin and repeat as above, till we do not get any pink colour after boiling for 1 hour.)

From the number of c.c.'s of Amm. Acetate used, the strength of the solution can be calculated.

Wt. of set cement 0·5 gramme.

No. of C. C. of Amm. Acetate used 6·5

No of C C. of Amm. Acetate Soln. used for 0·2 gm. of CaO = 33·6 c.c.

Therefore, strength of Amm. Acetate = 0·2/33·6 - 0·006 gm of CaO.
or, 1 c.c. is equivalent to 0 6 per cent of CaO.

For 0·5 gm. of set cement we used 6 5 c.c. of solution.

Therefore, for 1 gm. we would require 13 c.c of solution.

Therefore CaO with set cement = $13 \times 0{\cdot}6 = 7{\cdot}8\%$, or say, 8%.

(Analysis done in Chemical Laboratory, Dalmia-Dadri Cement Factory).

Analysis of the above cement—

CaO	62·1 per cent
SiO_2	22·6 „
Al_2O_3	5·4 „
Fe_2O_3	3·3 „
MgO	2·5 „
SO_3	2·5 „
Loss	1·3 „
	99·7 per cent

APPENDIX III

For several years the author has been investigating the possibility of manufacture of a cheap cement in India. While constructing the different cement factories between 1937 and 1941 of Dalmia Group of cement factories at Dalmianagar (Bihar), at Karachi (Sind), at Dalmia-Dadri (Jind State), at Doundot (Punjab), at Trichinopoly (Madras), and of Assam Bengal Cement Factory at Chhatak (Assam), the author's query to the suppliers of cement machineries was— "Is it possible to have a cement factory with a small investment of capital ? and the reply was generally in the negative".

All these years, the author was experimenting to find out if it was possible to make the combination of lime and clay to produce cement, other than the burning at high temperature between 1200 to 1600 degrees Centrigrade. Some of the results have been described in the author's Paper C/39 and some more in this paper. The author developed a series of Specifications for the manufacture of cements and some of them have been printed by the Patent Office of the Govt. of India.

(1) *Specification No. 24777, 23rd December 1937.*

IMPROVEMENTS IN OR RELATING TO MANUFACTURE OF CEMENTING MATERIALS

It describes a method of manufacturing cementing materials, such as cement and hydraulic lime for the constructional works by mixing together slaked lime and clay and burning the same in ordinary kilns, lime kilns or cement kilns with some gypsum,
ditto with jhama
ditto with cement
ditto with combination.

From the author's experiments in Sheet 1—Group A (Expts. 1-7), which dealt with slaked lime, jhama and gypsum, the author got very excellent results with lime, exceeding the strength of portland cements Group D, Expts 14, 15, 16-on lime, jhama, gypsum, cement-gave also very good results. Now by burning a mixture of lime and clay, we effect a chemical combination of lime and clay to form Calcium silicate & Calcium Aluminate, which in turn accelerate the initial setting and strengthening the mortar So this Cement will be superior to those described in Group A & B, C, D, E, F, G, and H.

(2) *Specification No. 25205, 23rd December 1937.*

IMPROVEMENTS IN OR RELATING TO MANUFACTURE OF CEMENTING MATERIALS.

It describes an improved manner of manufacture of cementing materials in which over-burnt bricks called jhama or picked jhama are ground finely and mixed up with cement or mixed up with cement clinker and a small percentage of cement gypsum finely ground and all ground finely.

This is about silica cements. Author's Expts 29 to 43 show that with 75/25 mix, we get great increase, both in initial and final strength and with 70/30, we get highest increase in final strength, much above the mother portland cement itself

(3) *Specification No. 25806, 25th October 1938.*

IMPROVEMENTS IN OR RELATING TO MANUFACTURE OF CEMENTING MATERIALS.

It describes a method of manufacturing cementing materials, which consist in making an intimate mixture of slaked lime or hydraulic lime with soorkhi (which is brick dust of soft, hard or vitrified bricks or of other kinds of burnt clay) with a small percentage of Gypsum or Plaster of Paris, with or without the addition of some cement.

Ditto with or without the addition of some silicate of soda.

Expts	in Group	A	—	(Expts. 1-7)
	in Group	D	—	(Expts 14, 15, 16)
	in Group	H	—	(Expts 26, 27, 28)

showed the great strength developed by this process

(4) Specification No. 27112, dated 5th January 1940.

IMPROVEMENTS IN OR RELATING TO MANUFACTURE OF CEMENTING MATERIALS.

The invention is an improvement in or relating to manufacture of cementing materials and this is a modification of author's prior Indian Specification No. 25805 of 1938, which consists in making an intimate mixture of slaked lime or hydraulic lime with soorkhi (which is brick dust of soft, hard or vitrified bricks or of other kinds of burnt clay) and a part of Plaster of Paris or Gypsum, with or without the addition of cement or cement clinker and where necessary with the addition of a small percentage of soda silicate.

The object of the author's present invention is to modify this method so that it may be applicable to make easy the manufacture in all places in British India.

With this object in view, author's invention is a thorough mixture of lime and soorkhi specially made, ground finely with a small percentage of Gypsum or Plaster of Paris. The soorkhi is specially made by burning clay with a mixture of lime or limestone powder and the mixture is taken as a substitute of clay in the manufacture of soorkhi. This cementing material can be used with additional part of ordinary soorkhi, sand, cinder, ballasts, shingles or other materials, both in mortar and in concrete. The percentage of clay or lime or limestone powder can be varied as desired and that will be dependent on the temperature of the kiln, where the clay mixture is burnt

In European countries, natural puzzolanas are available. The puzzolanas are of volcanic origin. They are ground very finely and used with lime. Many experiments had been done in Germany with German puzzolana called Trass. From records we find that the result of experiments with lime-trass mortar in the proportion (by weights)

Hydrated lime ..	1
Trass ground very finely—	4
Standard sand	15

gave a tensile strength per sq. inch as follows :—

7 days	—	238	lbs. per sq. inch.
28 "	—	366	" " "
90 "	—	415	" " "
1 year	—	437	" " "

With ordinary lime-soorkhi mortar, such results are not possible in 7 days, but possible with soorkhi specially made. Soorkhi specially made as described before can be described as artificial puzzolana.

The second modification of author's invention is to add some cement up to 50 per cent of the total weight of mortar with the lime soorkhi mortar as described before. The object of adding cement is to start initial set in the mortar earlier. As cement contains gypsum, it may not be necessary to add additional gypsum in many cases. Thus, the mixture will be lime

and soorkhi specially made, ground finely, and mixed up with a proportion of cement, varying up to 50 per cent of the total weight of mortar. The resultant composite mortar will behave in strength and setting more or less like portland cement mortars

It is generally known that in India, old practice to improve the lime soorkhi mortar was to add sugar, gur (sugar candy) molasses, catachew and several other country products, such as Bael fruit, Methee (a kind of pulse), tamarind mixed up with water According to author's invention, these materials can be used with the finely ground lime-soorkhi mortar and these will strengthen the mortar further. These materials can be added separately or in combination of two or more with the lime-soorkhi mortar.

It is to be noted that the alteration of proportions or the addition of such other materials, as cinder, sand etc. finely ground will not vitiate the spirit of author's invention In all cases, lime and soorkhi specially made, can be ground together or ground separately and then mixed up together. The lime can be hydraulic lime or hydrated lime.

So by that invention it will be possible to produce a lime or cementing material which will rival portland cement in strength but will not require the heavy initial outlay of money in the manufacture of portland cement. The grinding of the cementing materials may be done dry or with water as required. The lime described in the specification can be either slaked or hydraulic lime.

APPENDIX No. IV

Testing of cement—In the experiments for tensile tests, the author used water at 8½ per cent for Dalmia-Dadri Experiments and at 8 per cent of the weight of cement and sand for Dalmianagar Experiments. In these tests the briquettes in two places were made by two Gaugers The Results differed to a certain extent due to later gauging at Dalmianagar, after about 2 weeks, also due to different amount of compaction of the briquettes by two different Gaugers The amount of compaction varied according to the capacity of the Gauger.

In this connection, the author's experience at Baghdad in 1941 about testing of cement will be greatly convincing This relates to the acceptance of Dalmia Cement by the Iraq Govt, Baghdad, early in 1941. The Chemical Examiner of the Iraq Government tested Dalmia Cement from Karachi Factory with 3 times the weight of standard sand and 7.8 per cent water The strength obtained by him was in 3 days less than 300 lbs. per sq in. and in 7 days less than 375 lbs. per sq. in. and thus the cement was rejected as not complying with B.S S. The author went to Baghdad in February 1941 with a Gauger from Dalmianagar Cement Factory and the Gauger made, in presence of the Chemical Examiner of Iraq Government, the briquettes with Dalmia Cement and standard sand in 1.3 proportion and 7 8 per cent water. The strength obtained was above 400 lbs per sq in. in 3 days and above 500 lbs per sq. in. in 7 days Thereupon the Chemical Examiner took fresh samples from the same stock as before and made 1 3 mortar briquettes with 7·8 per cent water This time he got the strength of briquettes about 350 lbs per sq. in. and about 425 lbs per sq in in 7 days and subsequently passed the cement as complying with B.S S.

Then the question arose why the strength of the same cement with the same quality of sand and same proportion of water varied in strength by about 100 lbs. per sq. in. and what was the cause of such a big difference.

On closer investigation it was found that the difference in strength was due to different degrees of compaction of the briquettes.

All briquettes were made in standard moulds; on weighing some of the wet briquettes in Case I, the weights were found to be 149 to 150 grammes; in Case II, 160 to 161 grammes; in Case III, 155 to 156 grammes.

The strength of briquettes varied considerably according to the weight of the briquettes i. e. according to the compaction. The difference in strength was about 100 lbs. per sq. inch. Thus the strength depended upon the capacity of the Gauger to make compaction of the briquettes.

In standard Tension tests, that should not be the case. Tests done by different men should give the same or similar results.

In Compression tests as set up by the new British Standard Specification, 10 per cent water is added for making Test specimens. In Tension tests too that should have been the standard.

It will be a good thing if the Indian Roads Congress revise the B S.S. for cement tests and set up new Indian standard Specification with 10 per cent water. The personal element of the Gauger will be mostly eliminated in briquettes with 10 per cent water as after a few strokes with standard Spatula, water comes up on the surface.

EXPERIMENTAL RESEARCHES ON ARTIFICIAL POZZOLANIC CEMENTS

Group No.	Nature of experiment	Experiment No.	Series	Proportion of materials by weight: Slaked lime	Red surkhi	Over-burnt jhama	Gypsum	Burnt gypsum	Cement	Date of mixing	Fineness: 170 mesh %	72 mesh %	Setting time: % of water	Initial set mts.	Final set mts.	Soundness: Pat	Expansion Le Chatelier mm.	Experiments at Dalmia Dadri Cement Laboratory: Proportion of gauging with sand	% of water	No. of briquettes	Prop. with sand	Date of gauging	Tensile strength lbs/sq. in.: 3 days lbs	7 days lbs	14 days lbs	28 days lbs	90 days lbs	Experiments at Dalmianagar Cement Laboratory: Date of gauging	% of water	Proportions	Tensile strength lbs/sq. in.: 3 days lbs	7 days lbs	14 days lbs	28 days lbs	90 days lbs	
1		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
I	Lime-Jhama-Gypsum	1	A	1000		1000	100	--	--	[illegible]	48	0.64	26.1	80	120	Sound	Nil	1:1 0:1:6:3	11.5	15	1:3	[illegible]	-	75	144	350	595	[illegible]	8	1:3	-	Nil	50	95	315	1
		2	"	1000		2000	150	.	--	[illegible]	58	0.76	24.0	120	300	"	"	1:2 0:1:3:45	8.8	"	"	[illegible]	-	54	184	138	600	[illegible]	"	-	-	32	42	180	300	2
		3	"	1000		3000	200	--	--	"	26	0.241	"	60	100	"	2.5	1:3 0:1:1:6	8.5	"	"	[illegible]	-	92	237	421	695	"	.	"	-	22	102	260	542	3
		4	"	1000	-	4000	250	--	--	"	46	0.26	.	100	160	"	1.5	[illegible]	"	12	.	--	-	"	235	442	624	[illegible]	.	"	-	47	122	346	590	4
		5	"	1500		1000	125	--	--	[illegible]	40	0.36	30.4	55	120	"	1.0	[illegible]	"	"	"	[illegible]	-	62	21	63	314	"	"	"	-	Nil	40	100	200	5
		6	"	2000	-	1000	150	--	-	-	51	0.24	25.1	80	180	[illegible]		2:1 0:1:5:43	"	"	"	[illegible]	-	[illegible]	140	277	545	[illegible]	"	"	-	33	98	150	350	6
		7	"	1500	-	1000	250	--	--	[illegible]	77.2	0.36	30.1	40	70	"	-	[illegible]	"	"	"	"	-	25	52	118	212	"	"	"	-	Nil	23	62	133	7
II	Lime Jhama	8	B	1000	-	1000	--	--	-	[illegible]	29	0.24	23.4	32	70	Sound	1.0	1:1:6	"	"		[illegible]	-	116	208	346	453	[illegible]	"	"	-	63	160	193	350	8
		9	"	1000		2000	--		--	"	25.6	0.44	"	100	160	"	2.0	1:2:9	"	"	"	[illegible]	-	188	283	437	567	[illegible]	"	"	-	105	165	288	413	9
		10	"	1000	-	4000	--		-	"	17.9	0.36	23.1	110	200	"	0.5	1:4:15	"	"	"	[illegible]	-	225	354	552	515	[illegible]	"	"	-	122	180	292	530	10
III	Lime Jhama Burnt Gypsum	11	C	1000	-	1000		100	-	[illegible]	24.2	0.60	21.4	20	40	"	5.0	1:1 0:1:6:5	"	"	"	[illegible]	-	112	106	175	255	[illegible]	"	"	-	27	45	85	515	11
		12	"	1000	-	2000	--	150	--	"	6.6	0.40	21.7	40	80	"	1.0	1:2 0:1:3:45	"	"	"	[illegible]	-	64	137	183	435	[illegible]	"	"	-	45	80	165	270	12
		13	"	1000	-	4000	--	250	--	-	15.94	-	25.1	65	115	"	0.5	1:4 0:1:5:15	"	"	"	[illegible]	-	112	173	221	350	[illegible]	"	"	-	40	100	167	333* [illegible]	13
IV	Lime Jhama Gypsum Cement	14	D	1000	-	1000	100	-	500	[illegible]	53	0.75	25.3	80	118	"	1.5	[illegible]	"	.	"	[illegible]	75	110	152	310	625	[illegible]	"	"	30	65	160	270	455* [illegible]	14
		15	"	1000	--	2000	150	--	750	-	58	0.30	21.0	95	150	"	"	[illegible]	"	"	"	-	"	92	185	241	266	[illegible]	"	"	40	55	175	242	405* [illegible]	15
		16	"	1000		5000	300	--	1000	-	18.4	0.20	23.3	60	110	"	1.0	[illegible]	"	"	"	[illegible]	50	86	146	196	563	[illegible]	"	-	25	41	100	167	330	16
		16A	"	1000	-	1000	--	100	500	-	34.8	0.80	28.1	65	105	-	-	[illegible]	"	"	"	"	.	71	129	187	415	[illegible]	"	-	20	.	75	112	312	16A
V	Lime Red Surkhi Gypsum	17	E	1000	1000	--	100	-	--	[illegible]	9.6	0.40	21.4	30	60	[illegible]	1.5	1:1 0:1:6:3	"	"	"	[illegible]	5/7T		23	30	150	[illegible]	"	"	-	Nil	Nil	50	70* [illegible]	17
		18	"	1000	2000	--	150	--	--	[illegible]	9.12	0.60	26.5	105	180	[illegible]		1:2 0:1:3:45	"	"	"	[illegible]		50	56	83	350	[illegible]	"	"	-	16	60	78	225* [illegible]	18
		19	"	1000	4000	--	250	.	--	"	9.44	0.80	22.6	100	155	Sound	1.0	1:4 0:1:5:15	"	"	"	[illegible]		64	92	121	416	[illegible]	"	"	-	43	75	115	310	19
		20	F	1000	1000	-	-	-	--	"	14.5	0.36	28.1	50	80	"	-	1:1:6	"	"	"	[illegible]	-	30	108	129	200	[illegible]	"	"	-	Nil	35	77	118	20
		21	"	1000	2000		--	--	-	"	10.16	0.80	25.7	110	180	[illegible]	--	1:2:9	"	"	"	[illegible]	-	60	121	143	392	[illegible]	"	"	-	35	20	70	212	21
		22	"	1000	4000	--	--	--	--	"	8.2	0.50	22.2	75	165	[illegible]	1.5	1:4:15	"	"	"	[illegible]	-	64	118	123	316	[illegible]	"	"	.	20	32	100	265	22
VI	Lime Red Surkhi	23	G	1000	1000	.	--	100	--	[illegible]	14.5	0.56	28.0	25	60	"	2.0	1:1 0:1:6:3	92	"	"	"	-	25	52	38	171	[illegible]	"	"	-	"	26	50	100	23
		24	"	1000	2000	--	-	150		.	33.2	0.10	25.5	45	78	Sound	0.5	1:2 0:1:3:45	88	"	-	[illegible]	-	52	89	90	370	[illegible]	"	"	-	15	35	60	170	24
		25	"	1000	4000	--	--	250	.	"	11.5	0.60	28.7	136	208	"	.	1:4 0:1:5:15	85	"	"	[illegible]	-	56	129	104	337	[illegible]	"	"	-	33	60	80	1506* [illegible]	25
VII	Lime Red Surkhi Gypsum Cement	26	H	1000	1000	.	100	--	500	-	52	0.70	29.1	65	100	"	.	1:1 0:1:6:3	51	"	"	[illegible]	-	50	192	323	562	--	"	-	30	63	100	160	255	26
		27	"	1000	2000		150	--	750	-	3.74	0.40	26.2	35	85	"	Nil	1:2 0:1:3:45	52	"	"	[illegible]	-	166	242	435	615	"	-	-	40	103	160	290	315	27
		28	"	1000	2000	--	--	150	750	-	4.8	0.16	27.3	"	105	-	0.5	1:4 0:1:5:15	53	-	"	[illegible]	-	130	189	351	617	[illegible]	-	-	37	77	81	220	412	28
	Cement	29	I	--	-	.	--	-	100	.	6.2	0.04	21.7	70	102	"	1.0	10 30	78	15	"	[illegible]	465	496	525	572	585	"	"	"	415	460	475	485	580* [illegible]	29
	Cement-Jhama	30	"	--	-	10	--	--	90	.	5.2	0.28	21.8	75	105	"	0.5	9:1 30	"	"	"	[illegible]	445	470	533	567	700	1-	.	. "	403	420	470	600	605	30
		31	"	--	-	20	--	-	83	.	3.2	0.44	21.9	70	110	"	1.0	8 2:30	82	"	-	[illegible]	490	500	527	671	713	[illegible]	"	.	362	435	435	"	700* [illegible]	31
		32	"	--	-	30	--	.	70	"	6.9	0.20	"	98	165	-	0.5	7 3 30	"	18	-	[illegible]	437	438	485	654	"	-	.	-	353	330	405	470	565	32
		33	"	--		40	--	.	60	.	7.8	0.30	21.0	105	170	"	1.0	6:4 30	"	-	"	[illegible]	377	429	500	604	754	[illegible]	-	-	357	415				33
		34	"	-	--	50	--	.	50	"	10.2	0.10	"	100	150	-	1.5	5 5 30	"	"	"	[illegible]	309	316	385	521	600									34
	Cement-Lime	35	"			60	.	--	40	"	18.5	0.20	24.2	130	190	"	0.5	4:1:6 30	83	-	"	[illegible]	258	306	377	488	590								-	35
		35A	"	10	.	60	.	--	40	"	11.7	0.10	18.1	75	120	"	1.0	4:1 6 35	85	-	-	[illegible]	264	300	333	442	525									35A
		35B	"	--	-	70	--	--	30	"	11.7	0.80	25.0	140	210	"	"	3 7 30	83	.	"	[illegible]	194	292	370	465	604									35B
		35C	"	15	-	70	--	.	30	"	16.8	0.40	"	90	155	-	1.5	[illegible]	85	-	"	[illegible]	166	224	315	467	617									35C
	Cement Red Surkhi	36	J		10		--	.	90	"	7.8	0.40	22.0	85	125	"	0.5	9:1 30	"	"	"	[illegible]	425	465	500	562	664									36
		37	"		20	--	.	.	80	"	7.68	0.48	"	60	110	-	1.0	8 2 30	"	"	-	[illegible]	"	425	479	477	657									37
		38	"	-	30	--	--	--	70	"	10.0	"	"	"	145	-	5.0	7 3:30	"	"	-	[illegible]	351	389	462	518	675									38
		39	-	--	40	.	--	.	60	"	8.44	0.30	29.4	90	140	"	"	6 4:30	"	"	.	" "	380	417	450	562	667									39
		40	.	.	30	.	--	.	50	"	8.1	0.25	23.5	80	135	-	8.0	5 5:30	"	"	"	[illegible]	500	356	430	541	"									40
	Cement Red Surkhi Lime	41	"	-	60	-	-	--	40	"	3.90	0.10	22.6	80	132	-	5.0	4 6:30	"	"	"	[illegible]	256	350	433	-	510									41
		42	"	-	70	-	--	.	30	"	8.36	0.80	22.7	105	155	"	1.0	3 7:30	-	"	-	[illegible]	223	283	340	-	490									42
		43	K	10	60	--	--		40	"	5.5	0.48	25.8	70	110	"	5.0	4 6 1 33	"	.	-	[illegible]	211	340	423	-	600									43

* TOP FIGURE INDICATES STRENGTH AT 90 DAYS. LOWER FIGURES INDICATE STRENGTH AT NUMBER OF DAYS INDICATED

NOTE.— ALL MATERIALS WERE GROUND FINELY IN LABORATORY BALL MILL AT DALMIA DADRI CEMENT FACTORY LABORATORY AND WHERE THEY WERE MIXED SEPARATELY, THEY WERE MIXED IN THE BALL-MILL AGAIN FOR ABOUT 20 MTS. GENERAL TESTS WERE MADE AT DALMIA DADRI LABORATORY AND CONFIRMED AT DALMIANAGAR CEMENT LABORATORY.

REMARKS — TESTS AT DALMIA DADRI LABORATORY WERE MADE WITH FRESH CEMENTS & AT DALMIANAGAR CEMENT LABORATORY 3 WEEKS LATER, LATTER TESTS GIVE SOMEWHAT LOWER RESULTS THAN THE FORMER.

Mr. N.V. Modak (Chairman) called upon Mr. Datta to introduce his paper. Mr. T. C. Mitra introducing the above paper on behalf of Mr. Datta read the following note :—

I have great pleasure to introduce my paper on "Further Developments in Village Cement and High Silica Portland cements for the construction of Concrete Roads." This paper is in continuation of my last paper No. C/39 of 1939, which was read and discussed at the 6th Indian Roads Congress at Bombay, in December, 1939.

During discussion in 1939, Mr. N. V. Modak (Chairman of that Paper Meeting) said after general discussion of the paper—(Vide Page 21 (c)—Proceedings of 6th Indian Roads Congress—Discussions on Paper C/39).

"However, what is really needed now is that Mr. Datta should give us more data and bring his paper within the bounds of Practical Politics. With the materials now available, I do not think any Engineer will be able to achieve tangible results."

"I hope that Mr. Datta will continue his efforts undaunted in this direction, so that he will be in a position to give us next year fuller particulars as to the way in which to reduce the cost of cement."

In my reply to the discussion of Mr. Modak—[Vide Page 28 (c)], I said—

"I thank Mr. Modak for his suggestions and I hope to make further advance in this matter before the next Meeting of the Indian Roads Congress."

"Experiments have been taken up to find if we can produce the Village Cement without burning An advance has already been made in that line. It consists in making fine mixture of lime and hard-burnt surkhi and mixing some percentage of Gypsum and cement with it. If these Experiments produce the desired results, the production of Village Cement will be easier and cheaper."

The present paper deals in great detail the experimental results about this development. In the September Issue of the "Indian and Eastern Engineer", 1942, I wrote also an article on "Lime-Surkhi as a substitute for portland cement" in pp. 359-360.

Now coming to our subject—It will come as a surprise to many Engineers *to learn that Lime-Surkhi mortars can replace portland* cement under certain circumstances, a fact which has been established by recent research. Surkhi is powdered burnt clay, usually made by grinding red bricks. The use of Surkhi from over-burnt or fused bricks was practically unknown to general Engineers but modern experiments have shown that the best Surkhi for producing the strongest lime mortars come from these over-burnt or fused bricks, known as jhama ground very finely to cement fineness.

Surkhi was made from 1st class bricks, ground to pass B. S. Sieve 30

mesh per inch. The proportion of Lime to Surkhi was 1:3 by volume. The tensile strength of the Lime-Surkhi briquettes was·—

In 14 days .. 135 lbs per sq. inch.
In 28 days . 256 „ „ „ „
In 3 months . 399 „ „ „ „
In 6 months .. 428 „ „ „ „

The briquettes were immersed in water throughout the Tests. Compare these results with those of a similar Series of Tests on briquettes of lime and standard sand in the proportion of 1:3 by volume. The tensile strength of lime-sand briquettes was.—

In 14 days . 17 lbs. per sq. inch.
In 28 days 23 „ „ „ „
In 3 months 47 „ „ „ „
In 6 months .. 52 „ „ „ „

The Test Reports No. 3042 M. D. 6-1-37 lead to a very interesting conclusion *viz.* that the lime-surkhi mortar sets very hard in the presence of water, whereas, the lime-sand mixture does not. That proves that *Surkhi has hydraulic or pozzolanic properties which are absent in sand* Now we proceed with further investigations on the subject:—

1. What kind of Surkhi produces the strongest mortars ? What are the actions of under-burnt, well-burnt and over-burnt Surkhi ?
2. What proportions of Surkhi with lime produces the strongest mortars ?
3. How to increase the strength of Lime-Surkhi mortars still further ? What is the action of Gypsum ? What is the action of cement ?
4. What are the chemical reactions involved ?
5. What are the comparisons between portland cement and strengthened Lime-Surkhi, about constituents and about strength and life ? Comparison of free lime in set mortars in both cases.
6. What is the action of Jhama Surkhi on portland cement and how is the strength affected ?
7. What is the action of lime on portland cement-surkhi mortars and how is the strength affected ?

These investigations are really very interesting and lead to very important developments—(a) in the manufacture of Village Cement, (b) in the manufacture of High Silica portland cement, and (c) in the manufacture of Perfect portland cement.

1 What kind of Surkhi produces the strongest mortar ?

A long series of Experiments were undertaken on this subject at the Govt. Test House, Alipore, and the results were published in Indian Industrial Research Bulletin No 24, on—"Burnt clay or surkhi as pozzolana" by C A R Khan and Lal C. Verma, in 1941.

These experiments were conducted on lime-surkhi mortars, with fine grinding of the Surkhi and with different kinds of Surkhi, viz., under-burnt, well-burnt & over-burnt or jhama. The Surkhi was ground in a cast-iron Ball Mill to pass B.S. Sieve No. 30 and some

to pass No. 170 B.S. Sieve. The Tests were made with 1:3 proportion by volume and tensile strengths were determined at 14 days, 28 days 3 months and 6 months. The average results given at page 16 of the Bulletin were as follows:—

Brick Field.	Degree of Burning.	Lime-Surkhi ratio by weight.	Tensile strength in lbs per sq. inch.			
			14 days	28 days	3 months	6 months
Average of all	Under-burnt	1 : 8.0	119	189	275	317
	Well-burnt	1 : 9.0	135	236	356	386
	Over-burnt	1 :10.0	143	244	419	457

From these and other results the conclusion to be drawn is that over-burnt Surkhi with lime gave, on an average, 25 per cent. higher results than well-burnt surkhi, while under-burnt Surkhi gave, on an average, 14 per cent. lower results than well-burnt Surkhi.

In my Experiments with lime-surkhi mortars, made from well-burnt and over-burnt or jhama surkhi, I have arrived at similar results. (See Experimental Results at the end of Paper).

(2) WHAT PROPORTIONS OF SURKHI & LIME PRODUCE THE STRONGEST MORTARS.

From Experiments, I found 1.3 & 1:4 proportions giving higher results than 1·1 & 1:2. (See Experiment Results. Also, Vide "Chemistry of Cement & Concrete" by Lea & Desch on Pozzolana Cement).

We see that the strength developed in lime-pozzolana mortars varies with the ratio of lime: Pozzolana in the mix. At the early ages the maximum strength is obtained with the lime-pozzolana ratio of about 1:4 or even slightly larger but at longer ages the optimum ratio moves towards mixes of higher lime content and approaches about 1:3 to 1:2 at one year.

Feret found for plastic mortars - containing 1 part (weight) of lime & pozzolana to 3 parts graded sand,—the results shown below on specimens tested at the age of 1 year.

POZZOLANA	*Max. strength in lbs per sq. inch.*		*Percentage of lime giving max. strength.*	
	Bending	Compression	Bending	Compression
Trass	550	1640	35	26
Roman	504	1850	32	28

For a Trass Pozzolana, ground very fine and a burnt Shale Pozzolana, the Building Research Station, have given the following figures of mortar-briquettes of dry consistency.

Vide Annual Report, 1931.

Table XLVIII.

Effect of Pozzolana-lime ration on strength of mortars:—

Pozzolana	Mix. Proportions (weight)			Tensile strength lbs. per. in			
	Hyd. lime	Pozzolana	Std. sand	7 days	28 days	90 days.	1 year
Burnt-shale.	1	1	6	107	297	341	521
	1	2	9	133	322	459	560
	1	4	15	203	371	514	533
Trass.	1	1	6	213	361	448	482
	1	2	9	225	390	428	500
	1	4	15	238	366	415	437

In my experiments with lime-surkhi mortars made from well-burnt and over-burnt or jhama surkhi, I have arrived at similar results. In these experiments I ground the surkhi in the Ball Mill of the Charkhi-Dadri Cement Factory's Laboratory to a fineness, which would pass 170 mesh B S. Sieve and added sand to three times the weight of the mix of lime and surkhi From these experiments, I found that lime-surkhi mortars, especially from over-burnt surkhi when ground very finely to cement fineness, gave higher strengths with age. In about 3 months, their strength approached that of portland cement mortars. (See Experiments No. 1-29).

We thus find that one part of lime combines with 3 to 4 parts of jhama-surkhi, ground to cement fineness to produce the best results.

Referring to "Chemistry of Cement and Concrete" by Lea and Desch, we find that the best results were obtained by the combination of 1 part of lime with 4 parts of burnt clay ground to cement fineness and the free lime practically disappears after 4 weeks.

(3) HOW TO INCREASE THE STRENGTH OF LIME-SURKHI MORTARS STILL FURTHER ?

After carrying out further experiments, I found that the addition

of a small percentage of gypsum, say 5 per cent. of the weight of lime and surkhi, also ground to cement fineness gave a mix of lime-surkhi and gypsum mortar giving similar strength to that of portland cement in 2 to 3 months' time. (See Expts. 1-19).

ADDITION OF CEMENT—Lime-Jhama-Gypsum mix gives us a cement which sets comparatively slowly as compared to cement, but with age assumes similar strengths as portland cement in 2-3 months' time. From Expt. 29 on Portland Cement and Experiments 3 and 4, we find the strength of 1:3 briquettes as follows:—

Age.	Expt. 29.	Expt. 3.	Expt. 4.
3 days ..	465 lbs.		
7 days ..	498 ,,	92 lbs.	92 lbs.
14 ,, .	528 ,,	237 ,,	229 ,,
28 ,, ..	572 ,,	421 ,,	442 ,,
3 months ..	585 ,,	695 ,,	624 ,,

Experiment 3 is with 1 part of lime to 3 parts of jhama surkhi and 5 per cent. Gypsum.

Experiment No. 4 is with 1 part of lime to 4 parts of jhama surkhi and 5 per cent. Gypsum.

We find here that the Lime-Surkhi-Gypsum mortars exceeding portland cement in strength with age of 3 months, but at an early age of 1 to 2 weeks, the strengths were much lower. To compensate the initial development of strength, we can add some cement to the mix of lime-surkhi-gypsum and produce a pozzolana cement which will set hard early like cement and will develop great strength like portland cement with age.

4. What are the Chemical Reactions Involved?

When clay is burnt to jhama and is ground very finely to cement fineness, the silica which is the main constituent of the clay (roughly about 2/3rd of the weight) (see P. 76 of paper), goes in combination with lime in presence of water and forms hydrated Mono-Calcium-Silicates similar to portland cement (see P. 79 for the setting of portland cement). *Alumina*, etc., also go in combination with the lime.

5. Comparison with portland cement:—

Materials required for portland cement are:—

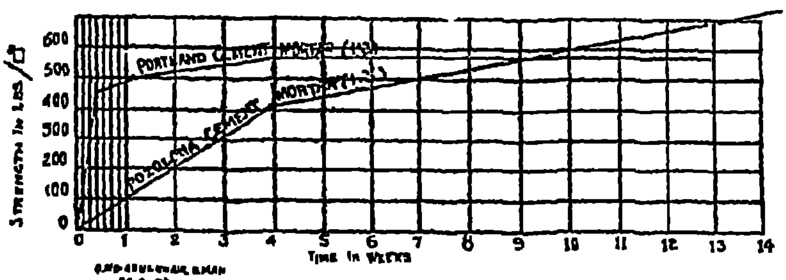
(a) Limestone.
(b) Clay.
(c) Gypsum.

Sometimes a little Laterite is added to adjust the composition of Alumina and iron.

By burning limestone we get lime; by burning clay to insipient fusion, we get jhama; so in Lime-Jhama-Gypsum mortar we are adding the same materials as cement. In case of portland cement, lime goes in combinaion with clay at high temperature say, between 1200° to 1600°C and a large

part of lime goes in combination with clay to form *Anhydrous Tri-Calcium silicate* and *anhydrous tri-calcium aluminate* (the major constituents). On adding water *tricalcium silicate* is decomposed into *hydrated mono-calcium silicate* & *Ca (OH)₂* (slaked lime).

Whereas in case of silica of jhama, lime goes in combination with the same in presence of water and forms similar hydrated *momo-calcium silicates.*



There is great similarity between portland cement and lime-surkhi-gypsum cement. Portland cement gets early strength as shown from the curves, whereas lime-surkhi-gypsum cement gets strength with age. With the addition of some cement to this mortar, the drawback of slow hardening is also removed.

That is our Village Cement i.e. a cement, which can be manufactured easily at villages, towns, cities, in different parts of India with the help of a Ball Mill.

(6 & 7). What is the Action of Jhama Surkhi on Portland Cement ?

What is the Action of Lime on Porland Cement-Surkhi Mortar ?

I have described that in great detail in my 1st paper and in this paper Jhama surkhi ground to cement fineness, when added to portland cement, increases considerably the strength of the same

We diagonised the reason for this increase in strength. Cement in setting liberates a considerable quantity of lime as free slaked lime. That was found to be about 11 per cent. of the weight of cement. The free lime goes in combination with the jhama surkhi and produces *Calcium silicate* and *Aluminate* thereby increasing the strength of the mortar.

Now we can assume that

(1) One part of lime goes in combination with 4 parts of surkhi, especially of jhama, ground to cement fineness to produce strong mortars.

(2) Cement contains about 11 per cent. of free lime when set and this percentage is dependent on the lime content of the cement.

Working on the above assumptions, we shall require $11 \times 4 = 44$ parts of

jhama surkhi to combine with 11 parts of free lime in the set cement.

44 cement
100 jhama
144 mix.

In 144 parts of silica cement, we get 100 parts of cement plus 44 parts of jhama. So the percentage will be

$144 : 100 : 100 : x$; or $x = \frac{100 \times 100}{144} = 70$ per cent. say.

So the best results will be with 70: 30 proportions, and that *is supported by actual experimental results* See Expt. in P 85 and my experiments 29-43.

Now suppose we add more jhama to the cement, that is necessitated by the free lime of the cement, say we make a mix—

Cement—50
Jhama—50,

Will the addition of lime help in the increase of final strength of the mortars ?

Let us see what of limo will bo required for that. In 50 parts, we shall have $50 \times 11/100$—5.5 parts of free lime. To neutralise 5.5 parts of lime, we shall require jhama 5.5×4.22 parts. So out of 50 parts, we shall take 22 parts for increasing the strength of the cement and there will be 50—22-28 parts as excess of jhama.

To increase the strength, we shall require $\frac{1}{4}$th lime *i. e.* $28 \times \frac{1}{4}$-7 parts of lime to be added to the mix of 50:50 and make it—

Cement—50 parts
Jhama—50 ,,
Lime—7 ,,

Now the question is—will 50:50:7 mix be stronger than 50:50 mix. Actual Experiments done by me recently had shown that with age we get higher strength with 50:50:7½ mix, much more than original portland cement.

Experiments at Dalmianagar Cement Laboratory on High silica cement.

Date of Sampling.	Expt. No.	Prop of Mat. Port. Cem	Sl. Lime	Jhama.	Date of Gauging.	Prop with Sand.	% of water	Tensile Str. in lbs. per Sq. in. 3 days	7 days	14 days	28 days	60 days	90 days	Rem.
10-3-43	41	100	—	—	9-3-43	1.3	8%	350	430	440	490	627	602	
,,	42	75	—	25	20-3-43	,,	,,	270	315	382	473	570	650	
,,	43	70	—	30	3-5-43	,,	,,	260	308	453	520	608	—	
,,	44	66	—	33	4-5-43	,,	,,	228	287	447	503	530	617	
,,	45	50	—	50	6-5-43	,,	,,	218	330	353	513	530	670	
,,	46	50	7-5	50	4-6-43	,,	,,	162	—	—	—	627	M (2-4 days)	

Expt. No. 41 is with portland cement only

Expt. No. 43 is with 70 30 proportion and here we find the tensile strength as 608 lbs. per sq inch in the place of 527 lbs. for portland cement.

Expt. No. 45 with 50 50 proportion. Here we find the strength at 2 months as 530 lbs per sq inch.

Expt. No. 46 with 50 50 7 5, we find the tensile strength in 3 days only 162 lbs. but in 2 months 4 days—627 lbs per sq. in That is much higher than portland cement itself

Thus Expt. No. 46 brings forward a very important matter in cement setting and development of strength in Cement Industry. We thus find that when there is excess of jhama mix in the cement we can add lime to make up of the final strength of the cement. Our assumptions are :—

(1) Cement contains about 11 per cent. free lime when it sets.

(2) Free *lime* goes *in combination with hard-burnt surkhi* (preferably of jhama), when ground to cement fineness in presence of water produces strong results in the proportion of 1 4 by height.

On these assumptions, we found the best mix of cement jhama as 70:30 and when we add lime to the mix we add also 4 times its weight of jhama to the same.

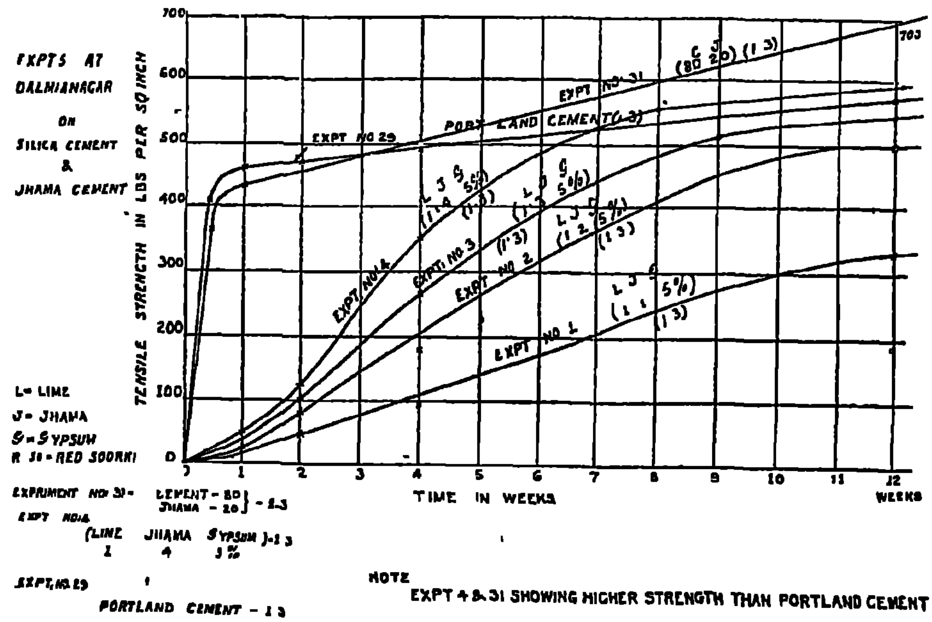
By this way, we can get Perfect Portland Cement in 70 30 mix, where all free lime in set cement is practically eliminated.

High Silica portland cement is also easily manufactured.

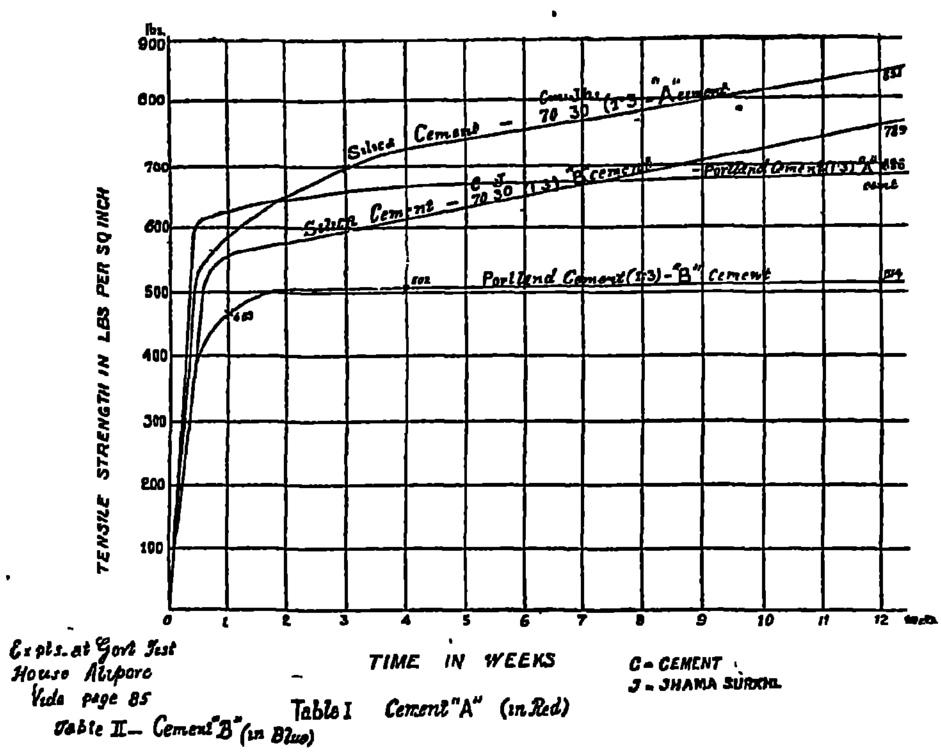
Village Cement is manufactured easily by mix of lime, jhama, gypsum and cement without going to the process of burning clinkers.

Now I invite you to discuss the paper.

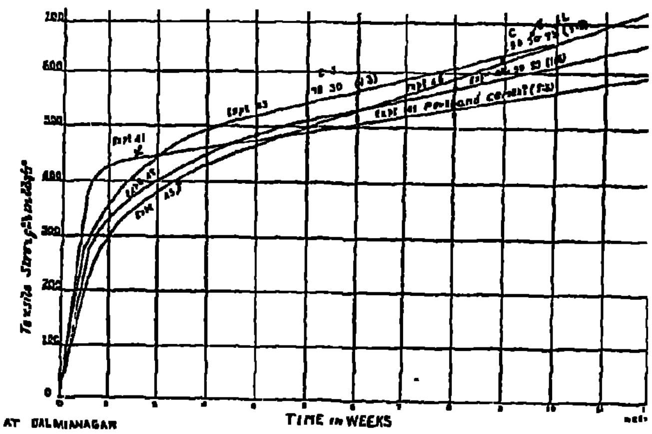
(*There was no discussion. Ed.*)



EXPTS AT DALMIANAGAR ON SILICA CEMENT & JHAMA CEMENT
TENSILE STRENGTH IN LBS PER SQ INCH
L = LIME
J = JHAMA
G = GYPSUM
R S = RED SOORKI
EXPT NO 29
PORTLAND CEMENT (1-3)
EXPT NO 31
EXPT NO 4
EXPT NO 3
EXPT NO 2
EXPT NO 1
TIME IN WEEKS
WEEKS
703
EXPRIMENT NO 31 - CEMENT - 80 JHAMA - 20 - 1-3
EXPT NO 4 (LIME JHAMA GYPSUM) - 1 3
EXPT NO 29 PORTLAND CEMENT - 1 3
NOTE
EXPT 4 & 31 SHOWING HIGHER STRENGTH THAN PORTLAND CEMENT



lbs.
TENSILE STRENGTH IN LBS PER SQ INCH
Silica Cement
Silica Cement
Portland Cement (1:3) - "B" Cement
Portland Cement (1:3) "A"
857
789
TIME IN WEEKS
C = CEMENT
J = JHAMA SURKHI
Expts. at Govt Test House Alipore
Vide page 85
Table I Cement "A" (in Red)
Table II – Cement "B" (in Blue)

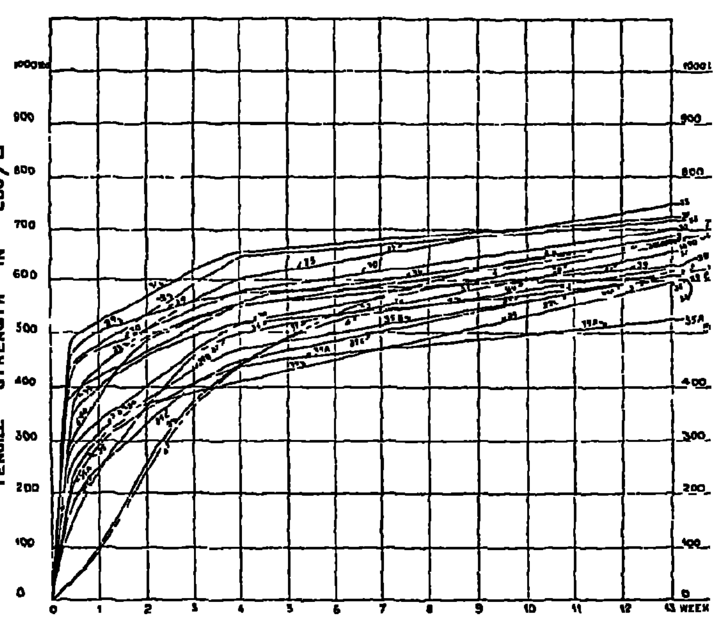


EXPERIMENT AT DALMIANAGAR
CEMENT LABORATORY

EXPT 41—ON PORTLAND CEMENT—(1:3)
EXPT 43—CEMENT 70 JHAMA 30—(1:3)
EXPT 45—CEMENT 50 JHAMA—50 (1:3)
EXPT 46—CEMENT 30 JHAMA 50 LIME 75 (1:3)

NOTE STRENGTHS IN EXPERIMENTS 43 45, 46 EXCEEDING PORTLAND CEMENT

—DALMIA-DADRI 1941-42.—

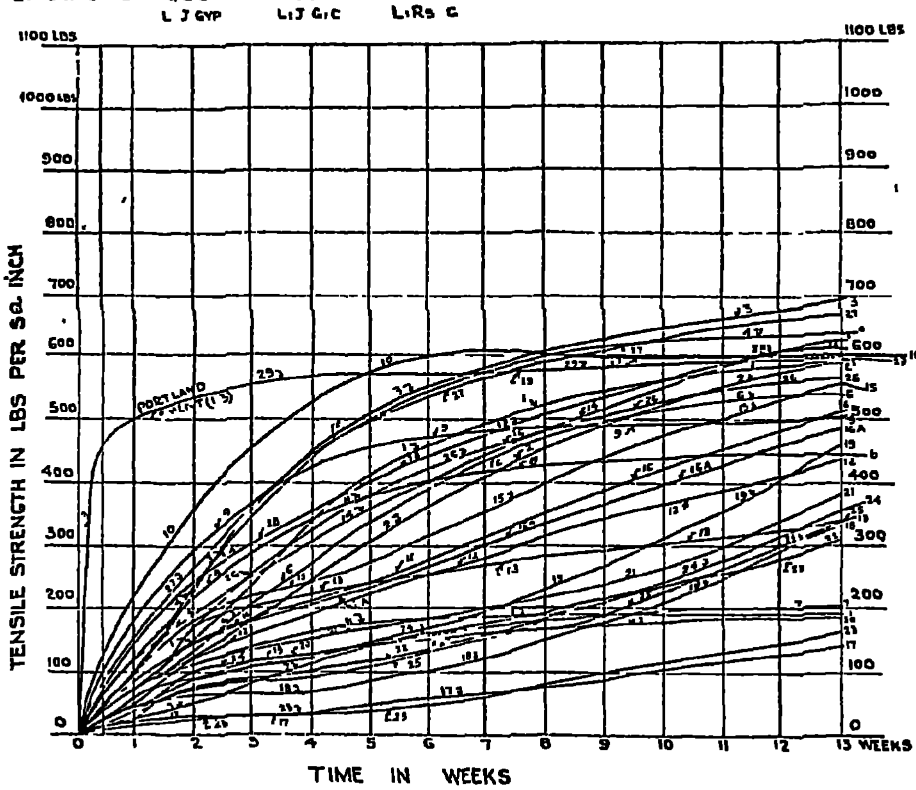


—TIME IN WEEKS—

EXPT 38	LIME NIL CEMENT 70	RED SOORKI	30		C : CEMENT
EXPT 4	LIME 1 JHAMA 4	GYPSUM	3%	1 3 WITH SAND	L : SLAKED LIME
EXPT 3	LIME 1 JHAMA 3	GYPSUM	5%	" " "	J : JHAMA OR FUSED BRICK
EXPT 10	LIME 1 JHAMA 4	GYPSUM	NIL	" " "	G : GYPSUM
EXPT 29	PORTLAND CEMENT	-------	—	" " "	
EXPT 31	CEMENT 80 JHAMA 20	-------	—	" " "	

'DALMIA-DADRI CEMENT-LAB-EXPERIMENTS

EXPERIMENTS 1,2 3 14,15 16 17 18 19
L J GYP L,J G,C L,Rs C



EXPERIMENTS WHICH RIVELLED PORTLAND CEMENT VIDE No 29 ARE Nos 3 4 10 14 1 27 28

PAPER No. F-43.

BOAT BRIDGE OVER THE INDUS AT GHAZI GHAT

BY

G. C. KHANNA, B.A., P.S.E.,
Executive Engineer, Multan.

CHAPTER I.

The River Indus and importance of Ghazi Ghat Crossing.

The town of Dera Ghazi Khan is connected with the rest of the Punjab by a road which passes through the towns of Multan and Muzaffargarh, and crosses the river Indus at Ghazi Ghat. The road is metalled and tarred throughout, except for a length of about eight to ten miles in the *Khadir* (bed) of the river. During winter when water is low, and river conditions are stable, a boat bridge is put up. This bridge carries light traffic, permissible under the rules in force. In summer, however, when the river is in flood, its course is changing, and its banks are not well defined, the boat bridge cannot be maintained and is therefore dismantled. A steamer plies in the river, and carries passengers and goods across. The steamer has a limited capacity, and makes normally one return trip each day.

After the outbreak of the war, the importance of the crossing at Ghazi Ghat increased on account of strategic reasons This crossing was a weak link in the chain of communications leading upto Quetta and other towns in Baluchistan. These towns are connected with Dera Ghazi Khan by a fair weather motorable hill road. The Government of India, therefore, considered it necessary to take steps to increase the capacity of the Crossing, so that it could cope with a greater weight and volume of traffic. During emergency the crossing should be capable of carrying heavy goods, vehicles, tanks, ambulances, etc., without any obstruction.

The River Indus.

Before giving a detailed description of the work that has been carried out in the past two years to meet the above requirements, it would be useful to give a brief description of the inconsistent* behaviour of the river in the neighbourhood of Ghazi Ghat.

In winter, that is, from the 15th October to about the 15th April, the water level is practically stationary and the discharge in the river varies from 20,000 cusecs to about 40,000 cusecs. The gauge† of the river at Attock is always below 10. The river flows in a steady stream,

*Gazetteer Muzaffargarh District, 1908, page 6.

"The inconsistency of the river is notorious, and has earned for it the nickname of 'Kanjari' ". It is said that "The river is like a prostitute which always keeps on changing its bed."

†A gauge is maintained at Attock near Khairabad, which gives information about the discharge of the river in advance. Attock is at a distance of 300 miles, upstream, from Ghazi Ghat and water reaches in about 3 to 4 days. (See Chapter IV, page 115).

there is no change in its course, and practically no erosion on either bank The main stream is constant in width and varies from 2000 feet to 2500 feet, which is easy to bridge. The banks on both sides being above the winter level of the river, keep dry, and satisfactory approach roads can be maintained. There are a few subsidiary creeks of the river which can be easily bridged. As there are no winds or sand storms, conditions are favourable for a boat bridge, which is maintained througout the winter.

In April the river begins to rise on account of the melting of snows and the discharge increases to about 1,00,000 cusecs. The velocity of water in the river increases and erosion of banks starts and the approach roads get under water. Winds and sand storms along with the waves which they set up, make conditions unfavourable and the boat bridge is dismantled.

During summer the discharge in the river varies from 1,00,000 cusecs to about 6,00,000 cusecs, attaining a maximum of 10,00,000 cusecs in abnormal floods The river generally attains its maximum discharge during the months of July and August, when its supplies are increased on account of monsoon rainfall in the hills and plains. The water level in the river rises by about eight feet and the area adjacent to the river gets under water. At the time of high flood width of the river including the creeks is about four to five miles. The maximum velocity of water is about 14 feet per second. The gauge at Attock in July and August is always above 30 feet, but in high floods, it may touch the figure of 50 feet.

Shifting nature of the river.

As the soil near Ghazi Ghat is sandy and alluvial, the river flows in a sinuous fashion, making meanders every two or three miles. The velocity of the main stream is generally very high, and in consequence scour takes place The scouring on one bank is accompanied by silting on the other. When the current is strong, erosion takes place on the banks. The erosion in one locality may continue for months and hundreds of acres of land including villages may disappear. The river has a great tendency to form islands and shoals, which makes it difficult for navigation.

* It may be of interest to give a brief account of the destruction of town of Dera Ghazi Khan by this river. In 1885 the river began to threaten the town, which had a population of about 20,000. The cost of private property as well as Government, and semi-Government buildings including the Cantonment, was about three to four crores of rupees. In 1888 it was decided by a conference of Railway, Irrigation and Buildings and Road Engineers to build an embankment running parallel to the river on the principle of Bell's Bund This embankment was about one mile long, and cost about Rs 5,00,000. About 6 million cubic feet of stone were used in its construction.

This embankment along with subsidiary spurs to strengthen it, stood the onslaught of the river up to about 1900, when the situation was described as serious. In 1901 Lord Curzon the then Viceroy of India, visited Dera Ghazi Khan, and it was consequently decided to undertake further works for the protection of the town.

*Punjab Rivers and Works by Bellasis.

All the 'Protective' and 'Diversion' works, which included bunds, diversion cuts, floating spurs, hurdle dykes with rows of 40 feet long piles, were carried out at an exorbitant cost; yet the menace to the town grew more and more serious. By 1908, all these protective works had been eroded and the town stood unprotected, exposed to the fierce attack of the river. During the next two years, erosion continued in the town itself, and the whole of it was destroyed in 1910. The solitary building which survived the deluge was the District Court buildings. After destroying the whole town, the capricious river changed its course again, and now flows at a site about three miles away from the old town of Dera Ghazi Khan.

"*The changes in the river occur with such irregularity, that it is impossible to forecast them." During the floods of 1942, for instance, the behaviour of the river was very peculiar. It shifted one mile westwards, at the site of the crossing. Five miles upstream, however, it shifted eastwards about three quarters of a mile. The maximum width of the river at the time of flood was about five to six miles.

The above facts will show that it is impossible to train a river like the Indus, except at a very exorbitant cost. Putting up a permanent bridge is out of the question, especially during the war. The site of the boat bridge as well as landing ghats of the steamer, change from year to year. In fact the site of the landing ghats of the steamer may change several times during one season.

*Punjab Rivers and Works by Bellasis.

CHAPTER II.

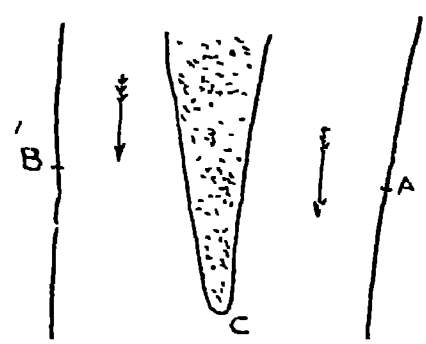
Arrangements for crossing the river in summer.

A steamer starts plying in the river from about the 15th April, and continues throughout the summer, up to about the 15th October. She can carry a maximum of hundred tons of goods and about eighty passengers, and is driven by 80 Horse Power steam engines, fed from two locomotive type boilers. She is a stern wheeler and moves at a speed of about 10-12 knots down-stream and about 4 knots upstream. The steamer can travel freely in water having a depth of 6 feet, but if the depth is less than 4 feet, she is likely to run aground.

It takes the steamer six to seven hours, to complete her journey both ways, including loading and unloading of passengers and cargo on both the banks. In times of abnormal floods, the journey may take as much as eight to ten hours.

The conditions necessary to maintain an efficient service, which causes least hindrance to passengers and transport of goods, are now described.

The steamer landings or ghats are at a minimum distance apart, so that the journey of the steamer is as short as possible. The approach roads are built so as to keep above the flood level, are reasonably short, and fairly passable. The depth of water near the bank is at least four feet, and the velocity of water is low. Only one or two places can be found to satisfy these conditions, and they are generally 6 to 8 miles apart. The length of the journey increases, as the river divides itself into two or three channels The steamer has to travel a considerable distance upstream or downstream to reach the junction of two channels. The steamer which starts at A (see Fig No. 1) must travel downstream up to point C which is the junction of two streams and travel upstream to point B on the opposite bank. She cannot travel straight across on account of the high ground in between.



To increase the carrying capacity of the crossing, two courses were open :—

(1) Purchasing one or two extra steamers.

(2) Reducing the journey of the steamer by increasing the number of landing grounds on both the banks.

As additional steamers were difficult to get on account of war, the only alternative that was feasible was to increase the number of landings by providing additional approach roads. The selection of additional landings was no easy matter, as the river was likely to change its course any time and leave the landings high and dry.

The advice of Engineers of Irrigation Department was sought, and they were of opinion that any work in the bed of the river was of a risky nature, and no guarantee could be given regarding its permanency. Anyhow some work had to be done and a scheme was worked out. The scheme, with certain modifications, was finally approved by the Government of India, after the site had been jointly inspected by the Chief Engineer, Punjab, P. W. D., Buildings and Roads Branch, and the Consulting Engineer, Government of India.

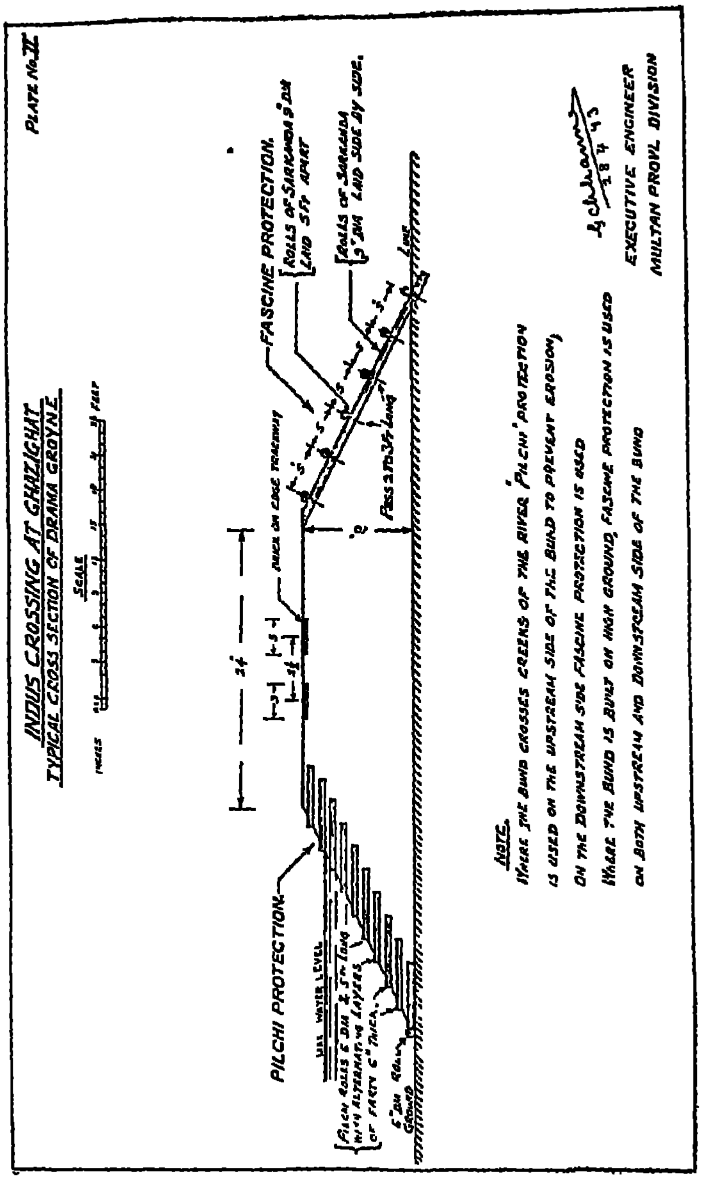
The work consisted of :—

(i) Providing an additional approach road on the East Bank This approach road runs in the North West direction and serves the landing stage No. 1 (See Plate No. I).

(ii) Widening the flood embankment on the Western Bank to 24 feet width and providing approach road to landing stage No. IV.

(iii) Widening and extending Draman Groyne to serve as approach road to landing stage No. III. Brick trackways have been provided over these, as the soil is sandy, and these bunds are about 8 feet higher than the ground level. The old approach road on the Eastern Bank to landing stage II, which had been functioning for last five or six years was also dressed and widened A typical cross section of the bund on the West Bank with its protective covering of grass is shown in Plate II.

The works were completed by May 1942, and the new Eastern Approach Road was working in the summer season. The river was receding from landing Stage II, which had been in service for a good many years. During the abnormal floods of 1942, the Draman Groyne was scoured away about one mile in length. Similarly the new Eastern Approach Road was also scoured away for a length of about three quarters of a mile. The approach road however kept on functioning until it was breached The breaches were repaired very soon, and normal working was resumed. It may be of interest to know that it was on account of the construction of this approach road that journey of the steamer was shortened, and the steamer could conveniently do two complete return trips every day. When communications to Quetta were entirely cut off during the floods, the steamer carried essential goods and foodstuffs by doing the extra trip every day. There was no delay in transport of supplies at Ghazi Ghat crossing whatever.


INDUS CROSSING AT GHAZIGHAT
TYPICAL CROSS SECTION OF DRAMA GROYNE
PLATE No. II
SCALE
PILCHI PROTECTION
FASCINE PROTECTION.
ROLLS OF SARKANDA 9" DIA LAID 5 FT APART
ROLLS OF SARKANDA 9" DIA LAID SIDE BY SIDE.
PILCHI ROLLS 6" DIA & 5 FT LONG WITH ALTERNATING LAYERS OF EARTH 6" THICK.
6" DIA ROLL
GROUND
24'
NOTE.
WHERE THE BUND CROSSES CREEKS OF THE RIVER "PILCHI" PROTECTION IS USED ON THE UPSTREAM SIDE OF THE BUND TO PREVENT EROSION, ON THE DOWNSTREAM SIDE FASCINE PROTECTION IS USED
WHERE THE BUND IS BUILT ON HIGH GROUND, FASCINE PROTECTION IS USED ON BOTH UPSTREAM AND DOWNSTREAM SIDE OF THE BUND
28 4 43
EXECUTIVE ENGINEER
MULTAN PROVL. DIVISION

diameter. It has four notches of one inch in depth, to receive both the trussed and the cross beams, and two deep notches, to receive the stiffening beams of such dimensions as to bring the top surface of the trusses and of the stiffening beams to a level. Fig. 5, Plate III, shows all details.

2. Trussed beams. See kk (Figs. 1, 2, 10, 11, 12, 13 & 14, Plate III).

They may be each of a single beam 30 feet long and 7 by 7 inches scantling, or each may be built of two pieces bolted together by round bolts of ¾ inch diameter, as shown in the drawings. Each beam runs in over the boat 1 foot, and rests on the gunwale piece in a notch 1 inch deep.

3. Stiffening beams. See aa (Figs. 1, 2, 4 & 5, Plate III).

These are stout beams of 10 inches by 6 inches scantling placed, as shown in the Plate, two to each boat. Each should, if possible, be a single piece of timber 26 feet 8 inches long, but may be in two pieces scarfed together. They are let into the gunwale pieces to such a depth as to bring their upper edges and those of the trussed beams to a true even surface.

4. Cross beams. See bb (Figs. 2, 4 and 5, Plate III).

These are 7 inches by 7 inches scantling and 13 feet 2 inches long, and rest on the gunwale pieces in notches 1 inch deep They merely rest on the gunwale pieces and are not fastened to them.

5 Stiffening planks. See cc (Figs. 2, 4 & 8, Plate III).

Each plank consists of two pieces One main piece 14 feet long and 12 inches by 3 inches scantling, and a minor piece (spiked to it as shown in Fig. 4) 12 feet long, 8 inches wide, and of such depth as to compensate for the difference in thickness between the trussed beams and the stiffening beams (*kk* and *aa*) which in the Plate is 3 inches. They are placed, as shown in the plate, near the ends of the stiffening beams, and in every case immediately under a roadway plank Each stiffening plank is tightly lashed at each end to the roadway plank immediately above it, by means of a chain so as to allow no play whatever.

6. A stiffening chain.

This is shown in detail in Figs. 6, 7 and 8 (*ee*) and as regards its general application, in Figs. 1, 2 and 3. Such a chain is passed round each projecting end of every stiffening plank, and of the roadway plank immediately over it, the hook with which it is provided at one end is passed into the nearest link, and everything is then brought home by the use of a rough wedge, *hh*. The centre of each chain is secured to the under part of the stiffening plank by a stout staple (*Fig. No. 8*) which passes entirely through the plank and is clenched on the upper side. The object is to prevent the chain from being lost in the confusion which often attends the dismantling of a bridge in a hurry, and often in the dark and in heavy weather.

7. Rough wedges. See hh (Figs. 1, 3 and 4, Plate III).

These may be about 18 inches long. Their use is obvious.

8. *Ordinary roadway planks. See dd (Figs. 1, 4, 5 and 9, Plate III).*

These are 14 feet long, 3 inches thick, and as nearly 12 inches wide, as may be practicable. The width for 6 inches at each end is to be reduced by 3 inches, as shown in Fig. 9 Each plank is to be furnished with two hard cleats 3 inches by 2 inches securely spiked on. See figure 9.

9. *Railing planks. See ff (Fig 15, Plate III).*

Each plank is from 17 to 17½ feet long, and they may be placed at any convenient distance apart The railing bars may be bullies of about 5 inches diameter, supported on three-nails of 1½ inches diameter of hard dry wood.

Small load carrying capacity of this bridge.

The boats are in equilibrium, and stay in their neutral position, when there is dead load on the bridge The queen post trussed beams rest on the gunwale of boats, and live load on a span adjacent to the boat, produces eccentric loading on it. The boat not only sinks, but also tilts considerably Its capacity for taking heavy loads is reduced on account of this tilting. The roadway rises or sinks with the rising and sinking of the boats and makes travelling over the bridge uncomfortable. Even though the total buoyancy of each boat is about 48 tons, the live load allowed on the bridge, was restricted to 2½ tons at a speed of 5 miles an hour.

Advantage of stiffening planks, beams, chains

The stiffening planks and beams are connected by a chain to each other, and to queen post trussed beams of adjacent span. They stiffen the superstructure of the adjacent spans, and help to reduce the up and down movement when live load is on the bridge The stiffening beams allow no play sideways to queen post trusses and therefore strengthen the bridge in the longitudinal direction also When the current is oblique, the thrust on each boat is sideways, and beams help to prevent any movement of the boat

Details of experiments for the development of the new type boat bridge

As the old type boat bridge could not cope with heavy traffic, alternative designs of bridges to carry heavier loads were considered. In the first instance rough designs of an entirely new bridge to carry loads up to I R.C. Standard loading, or 12 ton load were prepared, and it was estimated that the cost of the bridge would be about Rs. 180/- per foot run Rough design of steel pontoons, cement concrete boats, timber boats etc. were all considered, but were discarded, as the materials for these were extremely scarce. It was decided to make use of the existing equipment as far as possible, and work out such an arrangement which could take heavier loads As existing members of superstructure could take a load upto 8 tons only, it was decided to allow 7 tons vehicles over the boat bridge It was estimated that percentage of vehicles heavier than 7 tons would be very small, and these could be ferried across in the steamer or a large number of barges.

Experiments were, therefore, carried out with the existing equipment and boats Different arrangements of boats and superstructure were made, to determine the stability and load bearing capacity of different types of boat bridges. The experiments were made with a single boat, and with a pair of boats which were rigidly connected together. The first set of observation was taken when the boats were free, and the second set when they were fixed in a boat bridge, and connected with each other at varying distances by members of the superstructure.

First set of Experiments.

(*a*) *Single boat.*

Total buoyancy of each boat as calculated	..	= 48 tons.
Weight of boat	..	= 6.0 tons.
Displacement of boat in water, without any load on boat (*a*) Fig. 3 ..	..	= 10 inches.

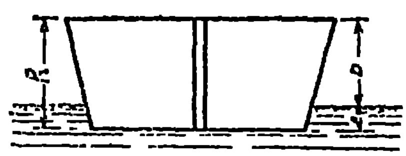


FIG 3

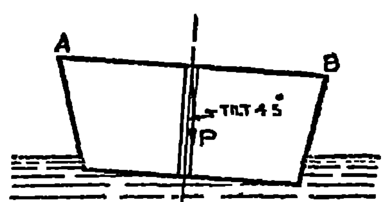


FIG.4

Displacement of boat with a weight of 6 tons over it equal to weight of superstructure.	..	= 1 foot 6 inches.
Displacement of boat with a weight of about 8 tons equal to live load ..	..	= 2 feet 6 inches.

Thus with a total dead and live load of about 20 tons on a boat centrally loaded, free-board would be 2 feet 6 inches. The buoyancy of a boat at various depths as determined theoretically is shown in form of a graph in Plate V.

Angular tilt of deflection of a single boat.

The boat was loaded centrally with a load of 6 tons equal to the weight of superstructure on it. The neutral position of the boat was marked with a plumb bob *P*. on the central prop. A load of ½ ton was placed at *A*, and then at *B*. Deflection of boat on each side of the neutral position was 4.5 degrees.

Again a load of 1 ton was placed at A and then at B. Deflection of boat on each side of the neutral position was approximately 10 degrees. The experiment proved the very unsatisfactory behaviour of a single boat, when the loading is not central, i.e., is on gunwales.

(*b*) A pair of boats was rigidly connected together. The buoyancy of a pair would be twice that of a single boat, and therefore was not determined experimentally.

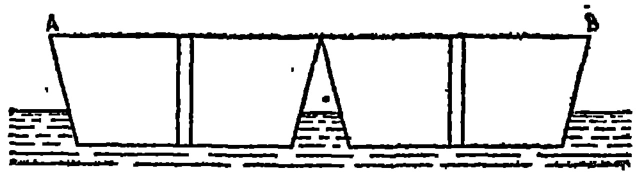


FIG.5

The angle of tilt with ½ ton load at A or B (See Fig. No. 5) was imperceptible, and with 1 ton at A or B was only 1 degree This showed the inherent advantage of a pair of boats if the loading is not central

Second set of Experiments: *With boats fixed in various positions in a bridge of boats.*

Staves were fixed on each side of the boat, on which neutral position of the boat was marked with pencil as shown in Fig No. (6).

FIG 6

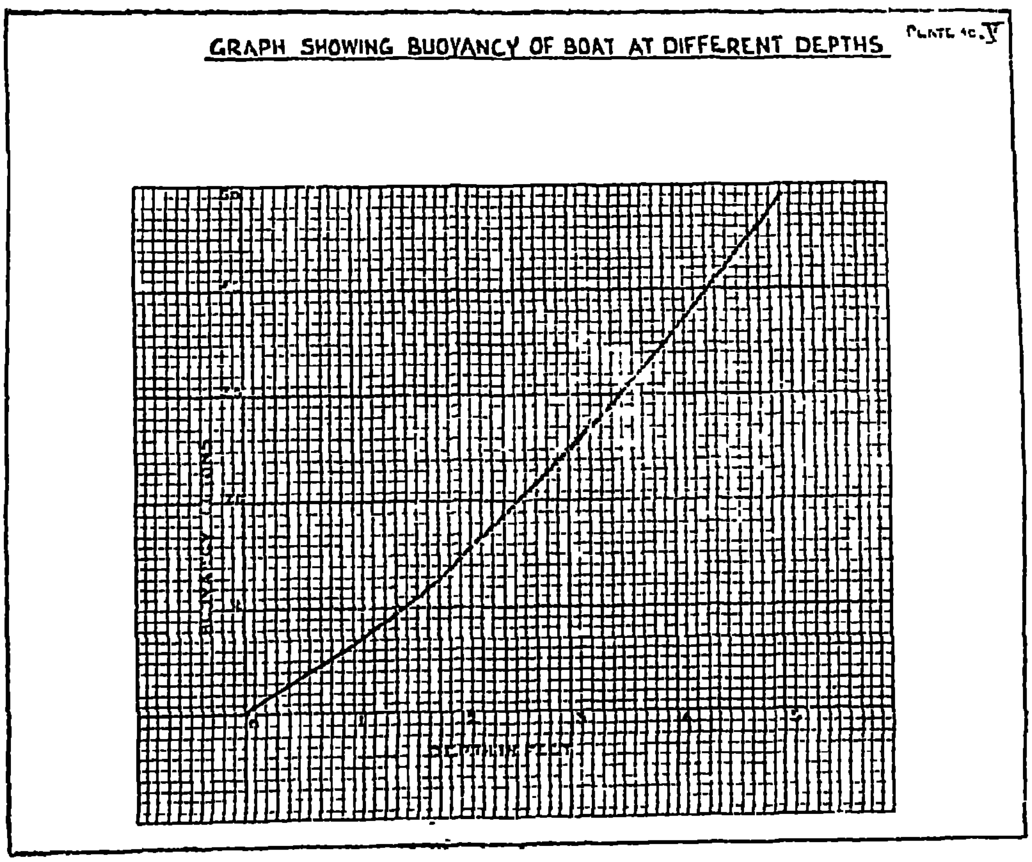
The motor vehicle was made to travel over the bridge, and when its load came over the boat, it rose or fell from its normal position The extreme positions were marked on the staves, and measured later on. Similarly the angular tilt was measured by a plumb bob fixed to a prop in the centre of the boat. The movement of boat consisted of two distinct movements, (a) angular tilt, and (b) vertical displacement on account of direct load.

Live load. A 7-ton truck with a gross load of 8 5 tons including its own weight was first passed very slowly over the bridge, and was made to stop over each boat or pair of boats Readings were taken in all the boats After that the truck was made to travel at a speed of 3 to 4 miles an hour, without stopping, and readings were again taken. The second set of readings were about 10 per cent higher than the first set. This shows that impact factor of 15 per cent assumed in design calculations is on the safe side See Appendix I, Page 126 For comparison, readings were also taken on the existing boat bridge, with an empty passenger lorry weighing 2½ tons These readings gave performance of the existing bridge and it was desired that the new bridge should not be worse than this

The various sets of observation for this load are given in Plate VI.

Plates VII, VIII and IX show the different arrangements of boats and trusses that were tried, and various sets of readings are recorded on each.

Plate VII shows twin boats with Gunwale Loading. This arrangement is not satisfactory as *list* is high When the fully loaded truck passed over the bridge, the superstructure formed a distorted *sine* curve, and there was considerable creaking noise which gave feelings of uneasiness Its chief advantage is economy in cost as well as ease in dismantling the bridge. In this type of bridge, at time of dismantling the roadway, planks over trussed beams are removed only, and the roadway planks over the boats are left, so that boatmen can walk about easily. The trusses, stiffening beams etc can easily be handled and placed on the boats The arrangements, shown in Plates VIII and IX, have this drawback, that


GRAPH SHOWING BUOYANCY OF BOAT AT DIFFERENT DEPTHS
PLATE NO. V
BUOYANCY TONS
DEPTH IN FEET
0
1
2
3
4
5

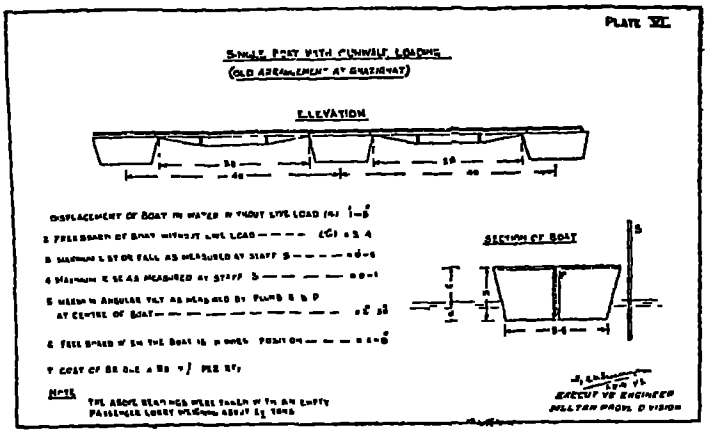


PLATE VI
SINGLE BOAT WITH GUNWALE LOADING
(OLD ARRANGEMENT AT GHAZIGHAT)
ELEVATION
SECTION OF BOAT

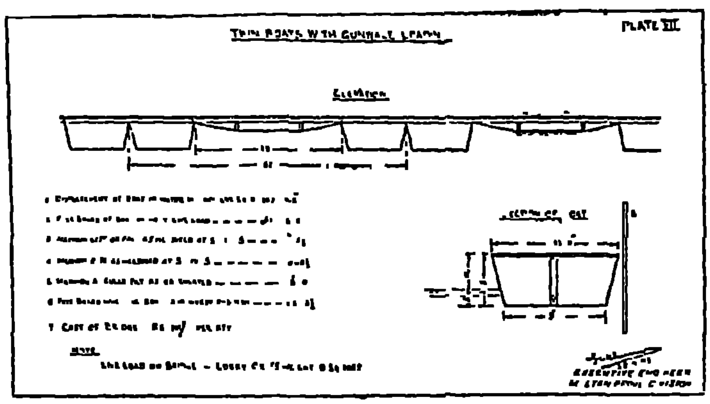


PLATE VII
ELEVATION

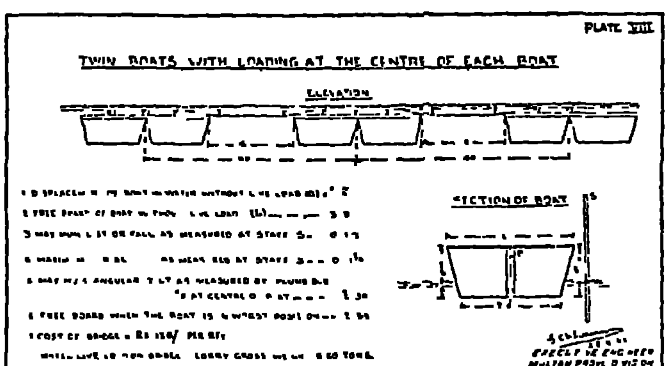


PLATE VIII
TWIN BOATS WITH LOADING AT THE CENTRE OF EACH BOAT
ELEVATION
SECTION OF BOAT

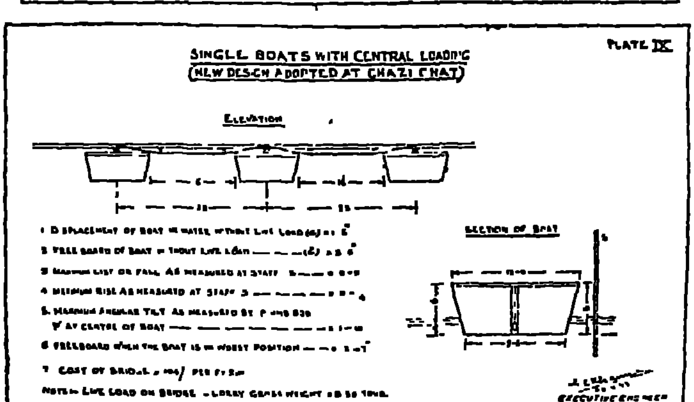


PLATE IX
SINGLE BOATS WITH CENTRAL LOADING
(NEW DESIGN ADOPTED AT GHAZI GHAT)
ELEVATION
SECTION OF BOAT

bridge cannot be dismantled easily. For these arrangements, greater time must be allowed for dismantling and a large number of crew must be employed.

. Plate VIII shows twin boats with load in the centre of each boat. This arrangement is more satisfactory than that shown in Plate VII. The clear water way is only 40 percent in this case. It is more expensive than arrangements shown in Plate IX.

Single boat centrally loaded. Plate IX.

In this case the load is at the centre of each boat; therefore angular movement is more or less eliminated, and the boat sinks gradually when the load comes over it The clear water way is about 60 percent. At time of heavy wind storm, it will offer greater obstruction than the old Gunwale Type bridge. The superstructure of the bridge is also raised by about 1 foot 6 inches, and may seem top heavy.

With this arrangement all the old members of superstructure, that is, planks, beams, etc. can be used. As the tilting of boats is very much less, wear and tear of members of superstructure especially planks is considerably reduced. The arrangement shown in Plate IX was finally approved.

Determination of stability of a boat from theoretical considerations.

The experiments carried out above showed that the boats were safe under dead and live loads, and would return to their normal position when live load was removed. From theoretical consideration it can be proved that these boats are in stable equilibrium under loads which are likely to come on the boat bridge. It was determined experimentally (Plate IX) that under live load, maximum tilt was 1 degree and 10 minutes. The minimum free board was 2 feet 7 inches.

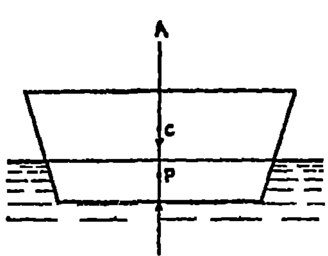


FIG. 7

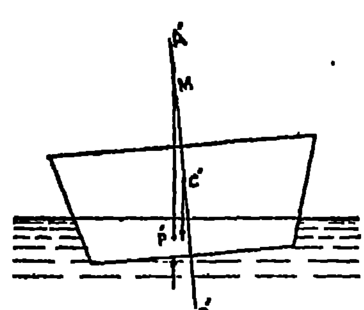


FIG. 8.

Fig. 7 shows a boat in its neutral position. The boat is kept in equilibrium by two forces which are acting on it, that is, its weight which is acting vertically downwards through its centre of gravity C, and water pressure acting vertically upwards through the centre of pressure P of the displaced volume of water. Both the weight and

water pressure are acting in the same line A B, and therefore balance each other

Fig. 8 shows a boat which has tilted from its neutral position. The centre of pressure has shifted to new position P'. If a vertical line is drawn through P' to meet A' B' at M, the point M is called the *meta-centre*. If M is above C', the equilibrium is stable, and the boat will return to its neutral position; if M coincides with C', the equilibrium is indifferent, if below C' it is unstable

Fig 1 on Plate X has been drawn to determine the stability of a boat, having a free board of 2 feet 6 inches and an angular tilt of 10 degrees, with a live load of 8 tons, and these adverse conditions cannot be expected in the boat bridge Even in this case the meta-centre M is above C' and the boat is in stable equilibrium.

Fig 2 has been drawn to determine the stability of the boat when free board is only 1 foot 6 inches, and angular tilt about 10 degrees. The total dead and live load on the boat will be about 30 tons Even with this load which is heavier than I.R C Standard loading, the boat is in stable equilibrium.

New Type Boat Bridge.

The details of strengthened boat bridge are very simple and are shown in Plate XI As far as possible the existing equipment, that is, roadway planks, trussed beams, boats, etc , have been used.

The boats are at 29 feet centres, and are fixed in their position by means of anchors Each of these boats carries 6 Nos saddle beams of deodar wood, size 13 feet long and 10 inches by 10 inches in section. The beams are placed 2 feet centres in notched Gunwale pieces, just over the ribs of the boats, so that loading from these beams is transmitted to the ribs

A long beam L (Fig 9) which is 14 feet long and 8 inches by 8 inches in section, is placed centrally over these beams and carries trussed beams Wooden pieces are fitted in the saddle beams, so as to prevent the movement of the long beam. 7 Nos trussed beams are placed over the long beam at 2 feet intervals Each trussed beam is placed in the centre of two saddle beams, so that tie rods do not touch any part of boat, or superstructure See Fig (2), Plate XI.

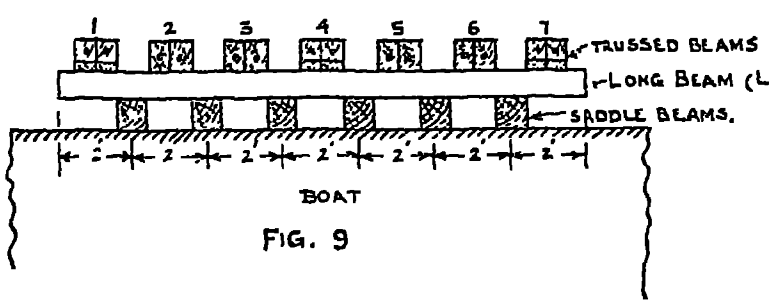


FIG. 9

The relative positions of saddle beams and trussed beams are shown in Fig. 9. It was found by calculations that the old type queen post trusses were not sufficiently strong to take up the heavier 7 ton lorry load. As these could not be entirely discarded these beams have been used at the two ends and the middle, that is, positions No. (1), (4) and (7) while at positions (2), (3), (5) and (6) new king post trussed beams of heavier section have been used (Fig. 9). Wooden pieces of timber have been placed below the beams Nos. (1), (4) and (7), so that the top height of these is the same to give even bearing to planks. The loading on the outer beams as well as central beams, that is, Nos. (1), (4) and (7) will be approximately half and they will be safe. The heavy vehicle loads will be travelling over king post trussed beams only, as the width of roadway is restricted.

King Post Trussed Beams.

The details of the king post trussed beams are shown in Plate XII. Its top compression member is 7 inches by 10 inches in section, which is heavier than that of the queen post trussed beam. The tie rod is, however, of 1¼ inches diameter, as against tie rod of 1⅜ inches diameter in queen post truss. The king post truss is heavier in weight and very unwieldy to lift and carry. The old queen post trussed beams will be gradually replaced by king post trussed beams when materials are easily available.

The roadway planks and railing planks are of the same size and shape as in old type bridge and are placed in the same manner. The span of these planks has, however, been reduced to 2 feet only. No stiffening planks or beams are used in this bridge as they are unnecessary. Long stiffening beams which were available from the old bridge are, however, used to connect the boats together as shown in Fig. 10.

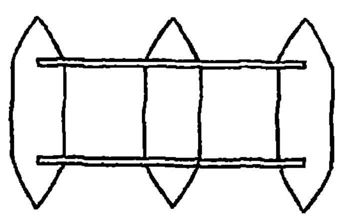


FIG 10

These beams are connected by chains fixed to the gunwales of each boat. When the current of water is slightly oblique, they prevent the movement of boats sideways.

Design of New Type of Boat Bridge.

The design calculations are straightforward and easy and are given in Appendix I, pages 126 to 139. When framing the estimate the trussed beam was designed as a queen post truss in the pattern of the existing truss. A queen post truss is not suitable for unequal heavy load, as a concentrated load on one post produces heavy negative bending movement at the

other post When there is load at P, and no load at Q, heavy, negative bending movement is set up at Q See Fig 11.

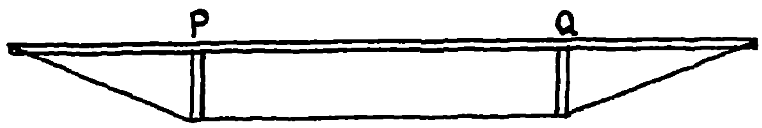


FIG. 11

The magnitude of this bending moment is maximum for all positions of the load Some of these beams were tested to destruction and the results of tests are given in Appendix IV, page 148.

Sal longitudinals and king post trussed beams were designed; finally king post trussed beams were adopted as these were most economical. The king post truss is very much cheaper than the queen post truss as the sectional area of the tie rod is half that in a queen post truss The total saving by adopting this design at Ghazi Ghat was about Rs. 10,000/- The breaking strength of these beams is given in Appendix IV (page 149).

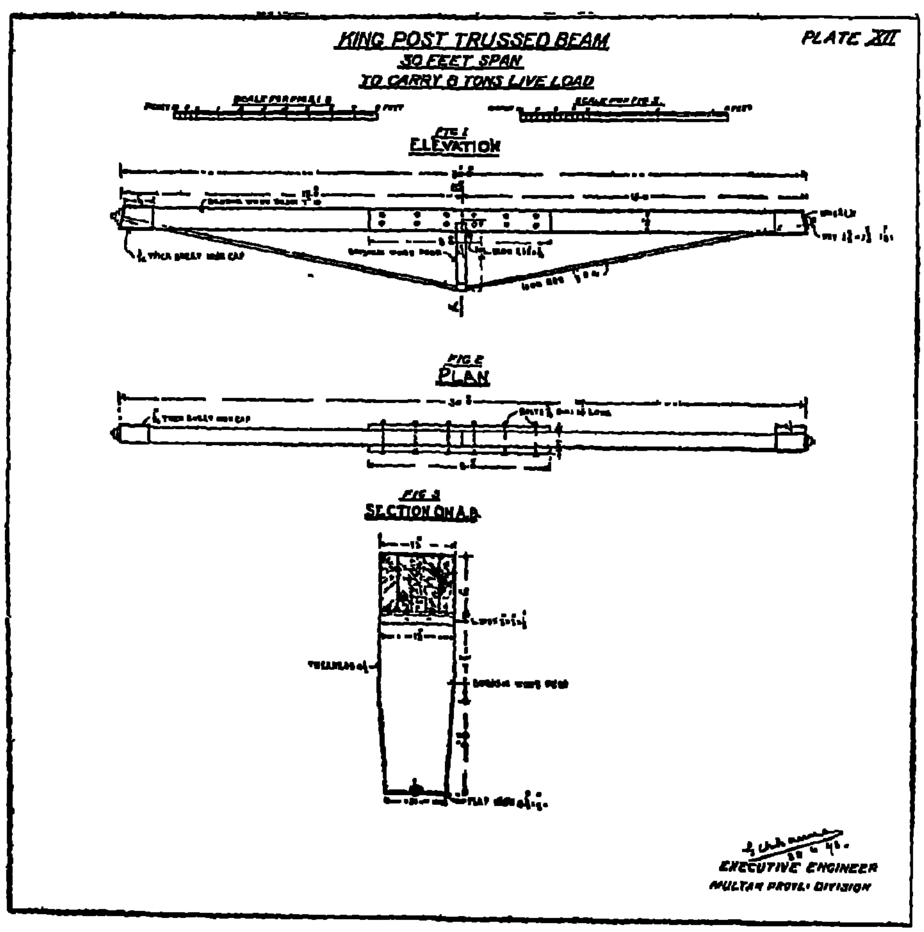
Design of boat.

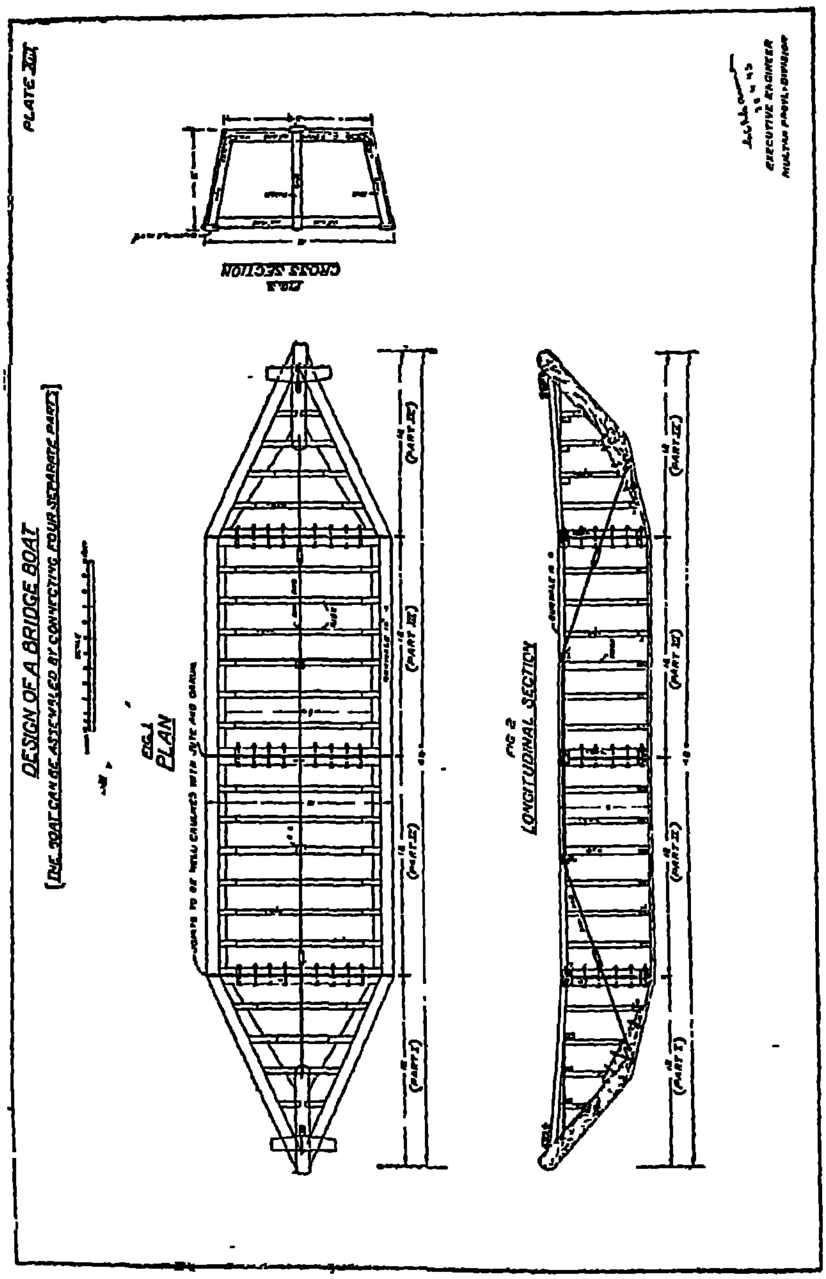
The structure of the boat is quite safe for heavier loads It was, however, found by calculations that when water gets low and a boat rests on the ground unevenly, the ribs of boats are unsafe The central 10 ribs have therefore been strengthened by adding another rib by the side of the old one In the new boats, size of the ribs in the centre of the boat has been increased from 6 inches by 3 inches to 7 inches by 4 inches. It is, however, necessary for the boatmen to see that a boat is surrounded on all sides by a *pushta* of sand about 1 foot thick, and bearing of boats is even, and covers a large area.

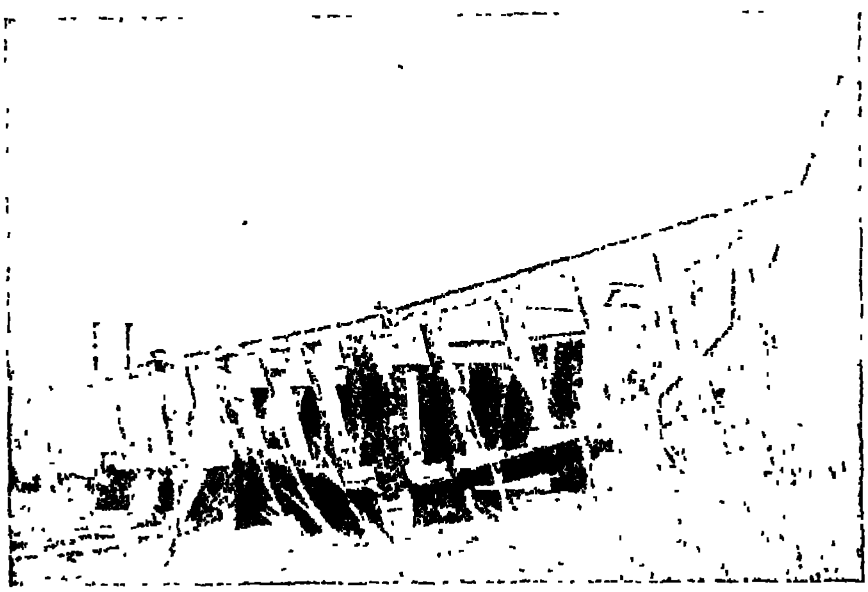
Design of a boat in parts.

Each of the boats is 6 tons in weight, 48 feet long and 12 feet wide. On account of the unwieldy size, the transport of a boat from one place to another is very difficult. Some of these boats were to be transported from Chichawatni to Ghazi Ghat, when the work of remodelling the bridge was started. The matter was referred to the railway authorities, who could not help, as their biggest wagons were unable to carry this load. Transport along the course of river is impossible, as rivers in the Punjab are interspersed with weirs and barrages required for Irrigation. There are no lock gates and it is both difficult and dangerous to cross a boat through the weir.

A design of a boat which can be separated into four parts is shown in Plate No. XIII. A boat has been built of this type and is working satisfactorily. Each of the parts is about $1\frac{1}{2}$ tons in weight and can be easily transported on road or by rail. At time of emergency the boats and equipment lying at one place can be easily transported to another place without much loss of time Another advantage of this type of


KING POST TRUSSED BEAM
30 FEET SPAN
TO CARRY 8 TONS LIVE LOAD
PLATE XII
FIG. 1
ELEVATION
FIG. 2
PLAN
FIG. 3
SECTION ON A.B.
EXECUTIVE ENGINEER
MULTAN PROVL. DIVISION


DESIGN OF A BRIDGE BOAT
(THE BOAT CAN BE ASSEMBLED BY CONNECTING FOUR SEPARATE PARTS)
FIG 1
PLAN
FIG 2
LONGITUDINAL SECTION
CROSS SECTION
EXECUTIVE ENGINEER
MULTAN PROVL. DIVISION



(1) A boat which can be separated into four parts for facility of transport. The sides planks being fixed to the boat.

boat is that wastage of wood used in the construction of boat is less. Gunwales are straight and not bent as in original design. The sides are also in separate planes.

Design of anchors.

Each boat is held in position by anchors on upstream and downstream sides. The details of anchor ropes, anchor blocks, quantity of stone in anchor blocks etc. are given in Chapter IV. Calculations for water pressure on boats, and wind pressure on the superstructure, and total load that comes on each anchor are given in Appendix I. These are based on constants given in I.R.C. Bridge Specifications. The total pull on each anchor works out to about 3 tons. The breaking strain on G. I. Wire anchors having six strands of wire No 8 is also about 3 tons. The *munj-ban* anchors have been tested in the laboratories attached to Engineering College at Moghulpura, and Engineering School at Rasul. The breaking strength of *munj-ban* anchors, $2\frac{1}{2}$ inches in diameter is about 1 to $1\frac{1}{2}$ tons. Two anchors are used on the upstream side in swift water and have been found always safe. It seems that constants assumed for wind and water pressure are high. As the boat bridge is dismantled in April, the velocity of water and winds do not touch their peak values, and therefore the pull on anchor ropes is well below the maximum.

Chain or Wire Rope Cable.

Two cables are fixed on the upstream and downstream side of the boat bridge, and their details are given in Chapter IV. Detailed calculations for these are given in Appendix I. Alexander Taylor suggests that the shape of the cable should be in the form of a catenary with a deflection of 1/8th of the span at the centre. The cable of the boat bridge at Ghazi Ghat has never been built in this shape, and is always straight. The cables are therefore straight from one bank to the other. The cables stiffen the bridge, and come into play when an anchor gets loose. Tension in the chain will depend upon the deflection that occurs when the anchor is broken.

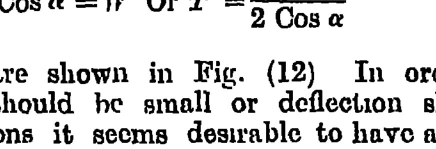


FIG. 12

Tension in the chain is determined by formula :—

$$2\ T \cos\alpha = W \text{ Or } T = \frac{W}{2 \cos\alpha}$$

T, α and W are shown in Fig. (12). In order that value of T should be small, α should be small or deflection should be maximum. From the calculations it seems desirable to have a chain which is loose, rather than one which is tight. The boats should be connected to the chains, so that they can slide. At present each boat is connected to the chain, and no movement between the boat and the chain is possible. The calculations will also show that the chain as used is unsafe for loads that are likely to come on it. Opinion of the members of the Congress are invited on the calculations that have been made, and on the exact function of the chain.

CHAPTER IV

Maintenance of Boat Bridge including details of erection and dismantling.

It has been explained before that during summer floods, the river changes its course considerably. The boat bridge cannot be erected at the same place every year on account of changes in the river A new site has to be selected every year and the following points govern the selection of site :—

(1) The river should be narrow, and should flow in a steady stream parallel to the banks

(2) The banks on both sides should be sufficiently high so that approach roads are always above the winter level of the river, and keep dry throughout the season.

(3) The soil on both banks should be reasonably hard, so that anchors for cables are fixed firmly and approaches are easy to maintain.

(4) As far as possible there should be no erosion on either of the two banks.

(5) The site should be such that central line of the boat bridge is kept at right angles to the flow of river The flow of current should be parallel to the longitudinal axis of the boats, so that thrust due to water pressure is even on each boat This is, however, difficult to achieve, as at some place or the other, the current is slightly oblique, resulting in lateral thrust on boats.

Tools, Plant and Stores.

Before starting erection, the following articles should be collected :—

(a) Stone boulders, and trangars made of *munj-ban* or wire netting for anchors.

(b) *Munj-ban* or G I wire ropes for anchors.

(c) Cables or chains required at upstream and downstream sides of the boat bridge, with proper means for anchorage.

(d) A few portable steel anchors, for anchoring ferry boats, and bridge boats near the banks A few bamboo poles for steering the boats, oakum for caulking the joints, buckets for baling out water and a rod with a hook for catching upstream anchor ropes released by front anchor boat Lamps and torches for watch and ward at night.

(e) Three or four boats of country type with oars for going from one place to another, dropping anchors, etc.

(f) Manila rope having a length of 500 feet or so, for anchoring one ferry boat, on the upstream side of the boat bridge.

(g) Motor Launch for bringing the boats into their proper position on the bridge. Without the use of motor launch, especially

in swift water, it is difficult to bring individual boats into proper position.

(h) A few carts or camels for carriage of boat bridge equipment like planks, beams, trestles etc. which cannot be brought in boats.

(i) First Aid Box with medicine chest. The work is very rough as heavy beams, and planks have to be lifted and therefore some boatmen are likely to get injured.

Determination of Span, etc.

The central line of the boat bridge is marked on both the banks and the span of the boat bridge is determined by triangulation. This is necessary so as to know the number of boats required in the boat bridge. The boats which are loaded with equipment for superstructure are now brought out into the main river from a creek, where they have been kept during summer. It is much easier to transport unwieldy beams and planks by means of boats rather than by carts or lorries, especially as the roads are slushy and soft at this time The boats are floated downstream or towed upstream until they are brought to the main river. They are kept moored to the bank where current is slow, until required.

Each boat is loaded with requisite number of beams, and planks required for one span of the superstructure The saddle beams and long beams are in proper position on the boat. The trussed beams are, however, placed upside down Five of the trussed beams are placed on the long beam and the remaining two along with planks at the two ends of the boat, so that boat is evenly loaded. Another advantage of having two long beams at the end is, that it leaves greater room for boatmen to work, when the boat is being shifted. With all the seven beams in position, there is always some congestion.

Bank From Which Erection Should Proceed

As mentioned above, the current is generally oblique and the bank where it hits is selected for starting the erection of the boat bridge. The erection will be started from end A (See Fig. No. 13).

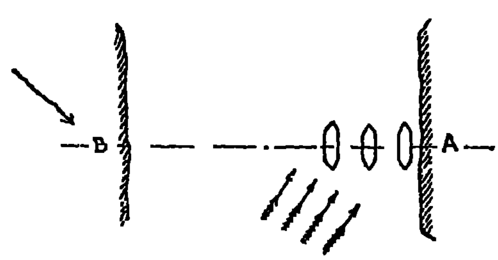


FIG 13

During erection the first boat is brought close to the bank 'A' and is then pushed out to its proper position The tendency of the current is to prevent the boat going too far, when it is pushed from the bank. If the boat were to be pushed the other way, its motion will be helped by the force of the current, and it may go too far and be out of control.

In the same manner other boats are pushed against the current, which retards the movement of each boat.

Details of End spans.

In the first span the beams carrying the superstructure are supported on one side on the first boat and on the other side on the bank The bank is properly dressed to provide even bearing place for the beams If the level of the banks is too low as compared to the level of the roadway in the bridge, a trestle is placed at this end. The plan of a typical trestle is given in Plate No XIV. If the difference in level is not too much, then either a beam, or a large number of roadway planks connected together are used to serve as bearing plates for trussed beams. These planks or beams are placed about three or four feet away from the bank, so as to be safe from erosion.

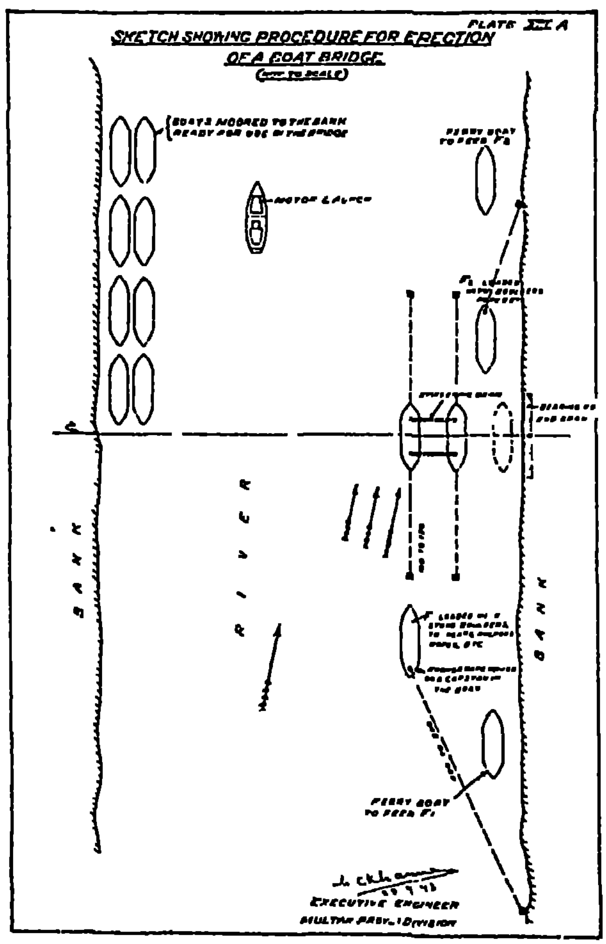
Erection

Two ferry boats which are used to drop the anchors upstream and downstream sides of the bridge are brought into the main river and anchored to the bank from where the erection is to proceed The ferry boat F 1 for upstream side, has an anchor rope 400-500 feet long and is anchored about 500 feet upstream of the boat bridge, (See Plate XIII A). This boat is kept about 100-120 feet away from the boat bridge, and can be manoeuvred to any position by increasing or decreasing the length of its anchor rope This anchor rope is wound on a capstan fitted into this boat, and by winding or unwinding this rope, its length can be decreased or increased This boat is kept loaded with stone boulders, trangars (nets) for stone boulders, and anchor ropes It is brought into the centre line of the position of the first boat in the bridge, at a distance of 100 feet upstream A trangar is filled with 20-25 cubic feet of stone, is tied with an anchor rope of 100 feet length and is dropped into the river.

The first boat is brought close to the bank, and its position is shown dotted in Plate No XIII A The anchor rope of this boat is floated down from the ferry boat, and lifted by boatmen standing on this boat This rope is given a turn round the bow or end beam of the boat, and is held at its other end by one or two men on the boat The boat is thus under control when it is pushed out to its normal position in the bridge

There are about 10 to 12 men on the boat and about 10 to 12 men on the bank These men lift the trussed beams and shift them slightly so that they are supported at one end on the bank The men on the bank hold these beams firmly, and the men in the boat raise them a few inches These men push against these beams, and boat starts moving The men in the boat keep these beams sliding until the boat comes to its proper position The anchor rope is then tied and the position of the boat is fixed. The trussed beams which were upside down are turned over and brought to bear on the long beam The two beams lying at the two ends of the boat are also placed at their proper position and roadway planks are laid over these The superstructure is stiffened and boat men can walk over

The ferry boat F. 1 has shifted in the meanwhile to the position of the second boat and has dropped down the anchor for this boat. The


SKETCH SHOWING PROCEDURE FOR ERECTION
OF A BOAT BRIDGE
BOATS MOORED TO THE BANK
READY FOR USE IN THE BRIDGE
MOTOR LAUNCH
BANK
RIVER
BANK
FERRY BOAT
TO FEED F1
EXECUTIVE ENGINEER
MULTAN PROV. DIVISION

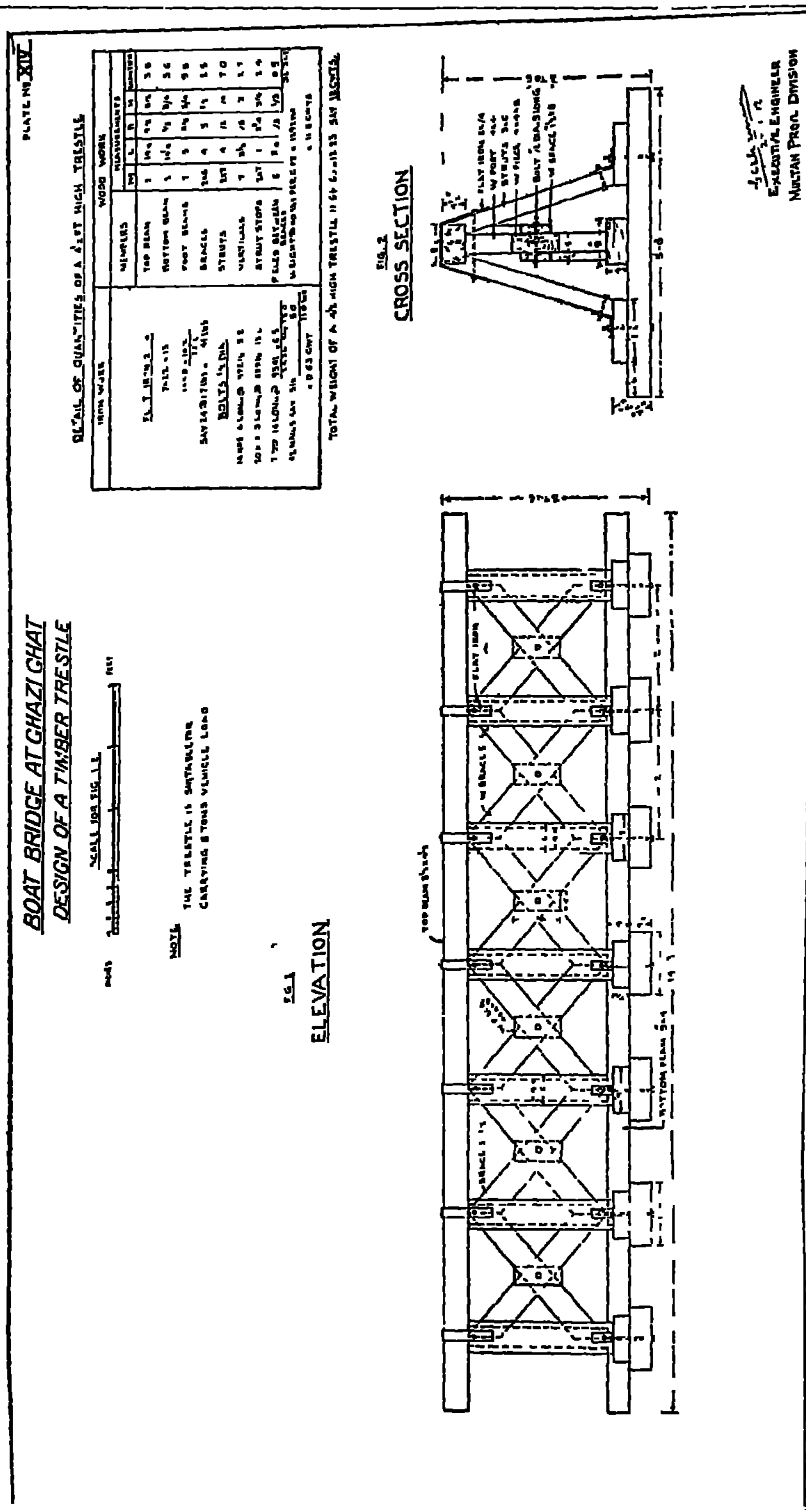


PLATE No XIV
BOAT BRIDGE AT GHAZI GHAT
DESIGN OF A TIMBER TRESTLE
NOTE
THE TRESTLE IS SUITABLE FOR
CARRYING 8 TONS VEHICLE LOAD
ELEVATION
CROSS SECTION
EXECUTIVE ENGINEER
MULTAN PROV. DIVISION

second boat is brought adjacent to the first boat by the motor launch, and is given its anchor rope which comes floating down from the ferry boat as before. The trussed beams are slightly raised by the boatmen on both the boats and pushed as before until the boat comes into its proper position, when the anchor rope is tied. These beams are then turned over and planks are placed in position.

The third boat is brought in position adjacent to second and erection continued in a similar manner.

The ferry boat F.2 is working on the downstream side, and is dropping anchors. This boat is, however, manœuvred into position by towing along the boat bridge which is being erected.

During erection stiffening beams which are about 27 feet long and 10 inches by 4 inches in section are bolted or chained to the gunwales of boats at their ends, so that the adjacent boats form a rigid frame and cannot be displaced from their true position The exact function of these has been explained in Chapter III (see Fig. 10, Page 101). If a boat does not come in the centre line of the boat bridge during erection, it can be brought to its true position by releasing or tightening the upstream or downstream anchors. If the boat has to be moved upstream, the downstream anchor is released and the upstream anchor is tightened and the boat moves upstream. When all the boats have come in position and roadway planks laid as described above the railings of the bridge are completed. The roadway planks are covered with 2 inches thick sarkanda grass which is kept well watered.

Cables.

In addition to the anchors, the whole bridge is held in position by two cables, one of which is fastened on the upstream side and the second on the downstream side to the end beams, or bows of the boat. These cables either consist of $\frac{3}{4}$ inch iron chains, or wire rope about 4 inches girth. Each of these cables is passed through two steel flats which are about 2 inches apart, and are fixed to the end beams at both ends of the boat There is a hole in these flats, and a bolt passes through the flats as well as a link in the chain, and thus connects each boat with the chain as shown in Fig. 14.

Alternatively it is tied by means of G.I. wire or *munj-ban* strings to the bow of the boat. These cables run throughout the length of the bridge and are firmly anchored on both sides.

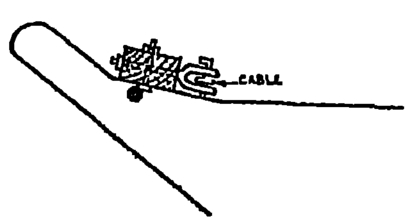


FIG 14

The ends of the cables are tied round a sleeper, which is placed in a pit about 8 feet long and 8 feet by 5 feet in section (depth depends upon the

level of subsoil water) The sleeper is tied down by wooden spikes fixed to the ground In addition it is loaded with stone boulders in wire crates as shown in Plate No. XV.

It takes about a week to complete the erection of boat bridge. In swift water the progress of erection is about 200-250 feet, while in slow water about 300-400 feet of bridge can be built in one day. A total of about 130-150 men is employed on erection, and the distribution is as below :—

20-30 men in bringing boats from creeks in the river to the bank where water is slow.

10-15 men keeping watch over boats which are kept anchored near this bank, until required in the boat bridge.

10-15 men help to feed the motor launch with boats, which brings them to position on the boat bridge.

20 men in the boat which is being pushed out into its proper position These men handle the trussed beams, as well as manipulate the anchors

14 men in the boat adjacent to the boat which is being pushed out These men hold the trussed beams at the other end

10-15 men looking after the boats which have come in position in the main bridge. These men caulk joints, observe leaks and help in other odd jobs

15 men laying roadway planks, railing etc.

8 men on anchor boat working upstream and dropping anchors.

8 men on anchor boat working downstream and dropping anchors

10 men in a ferry boat feeding the upstream and downstream ferry boats with stones, anchor ropes etc

10 men reserve for odd jobs, who also watch the centre line of the bridge

Bridge over creeks

There are several creeks of the river which have to be crossed. Smaller boat bridges, consisting of a fewer number of boats, are put over these If the depth of water is less, then trestles are used in place of boats.

A typical trestle bridge is shown in Plate No. XVI.

A large number of trestles of varying heights are kept in the godown and are used when required.

Difficulties in Erection of Boat Bridge.

Considering the mechanical devices available these days, the method described above for erection of boat bridge seems primitive and old-

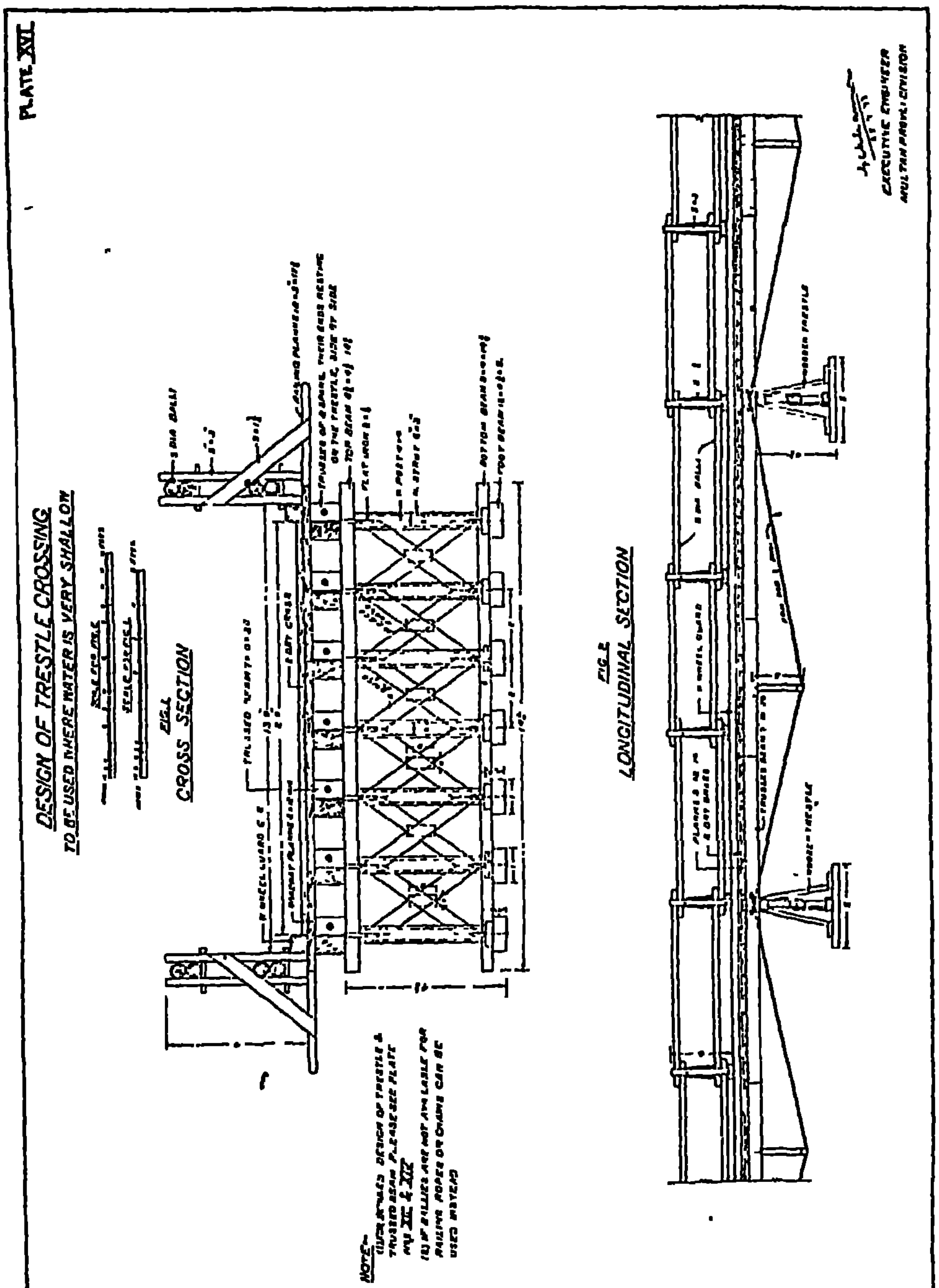
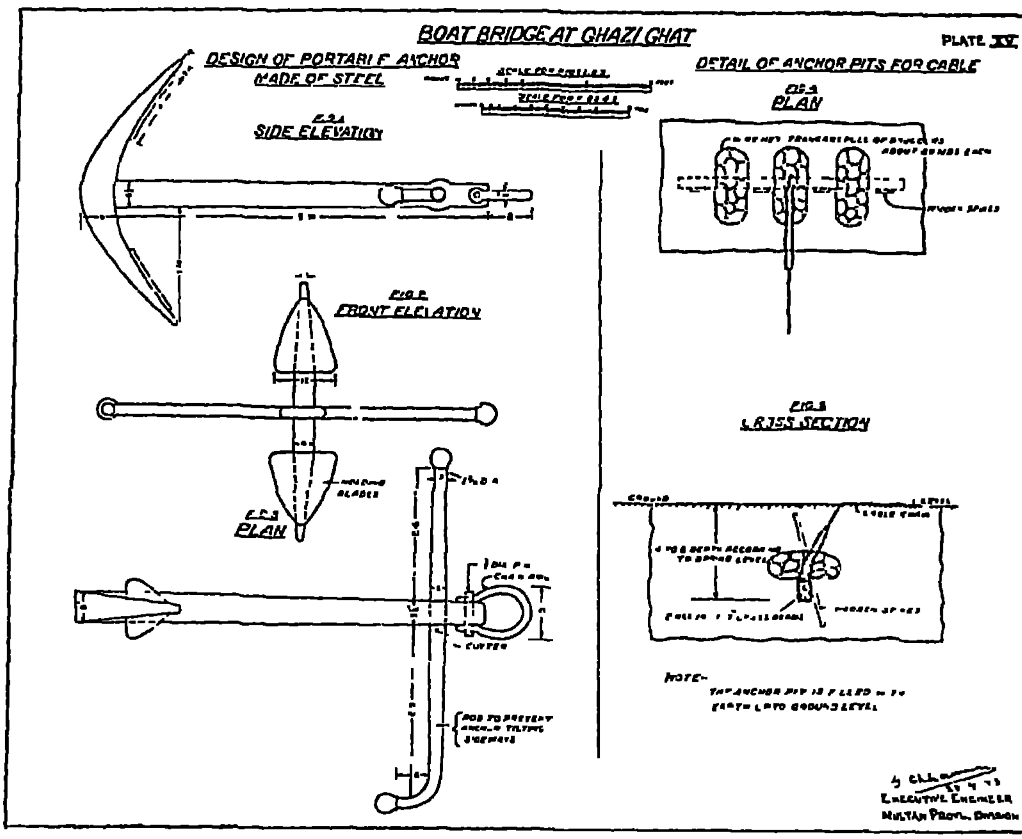


PLATE XVI
DESIGN OF TRESTLE CROSSING
TO BE USED WHERE WATER IS VERY SHALLOW
FIG. 1
CROSS SECTION
FIG. 2
LONGITUDINAL SECTION
EXECUTIVE ENGINEER
MULTAN PROVL. DIVISION


BOAT BRIDGE AT GHAZI GHAT
PLATE XV
DESIGN OF PORTABLE ANCHOR
MADE OF STEEL
SIDE ELEVATION
FRONT ELEVATION
PLAN
DETAIL OF ANCHOR PITS FOR CABLE
PLAN
CROSS SECTION
NOTE-
EXECUTIVE ENGINEER
MULTAN PROVL. DIVISION

fashioned. It is very laborious, and causes considerable delay and anxiety during the construction of the bridge. The handling of trussed beams is very difficult, as boatmen who manipulate these, are insecurely perched on the saddle beams. The process could be very much simplified if a few more motor launches were available. One motor launch or barge could be fitted with a crane to handle the trussed beams, and the erection of boat bridge could be completed within one or two days As the machinery is extremely scarce, new devices for simplifying erection will be considered after the war.

Approach roads.

The construction and dressing of approach roads in the river bed starts about a fortnight in advance of the construction of the boat bridge The alignment is straight, and as far as possible, is chosen through the firm and dry bed of the river. About four inches thick sarkanda grass is spread over the road, after it has been graded and dressed. Where the soil is sandy, rolls of wire netting are spread. It has been found by experience that if sarkanda is laid at bottom and top of the wire netting, the riding quality of the surface improves considerably, and maintenance is also reduced. In addition the life of wire netting is increased as wear is less. Sarkanda grass is available in plenty on both banks of the river, and is transported to the site by camels, boats, etc.

Maintenance of the Boat Bridge.

The Ferry Superintendent is in command of the ferry steamer and the boat bridge, and is under the administrative control of the Executive Engineer. The Ferry Superintendent lives in a house boat which is moored to a site near the boat bridge.

The darogha or an overseer is incharge of the boat bridge, and works under the direction of the Ferry Superintendent. The darogha lives at the site of the boat bridge so as to be easily available at time of need. He is assisted by a Jamadar, who is the head of all the boatmen The boatmen are divided into groups of ten, and each group is controlled by a daffadar or a mate.

The boatmen employed on the bridge must be of strong constitution and robust build, so that they can withstand the inclemencies of weather. They must be good swimmers and the Ferry Superintendent is expected to take a swimming test before employing them.

One man is generally allowed per boat, who looks after the boat, as well as the superstructure. It is his duty to bale out any water which may come through the joints inside the boat, caulk the joints, examine the anchor ropes, and cables, and also look after the beams, planks etc. on the superstructure. He also maintains his own section of the roadway, keeps it well covered with sarkanda grass, and occasionally waters it. It is found that the roadway planks which are kept moist, have a better life than the planks which are dry. The inside of boats is also kept wet, as moist timber expands and closes all joints and cracks.

When a boat runs aground on account of low water, the boatmen should see that the boat rests evenly on ground, and has a large bearing area, so that stresses on boat structure are reduced to a minimum.

During normal season, these men are more or less free, and a few of them are sent to the jungle to bring sarkanda grass, maintain approach roads and carry out other miscellaneous jobs At the time of flood or storm, each man comes to his post, and keeps guard over his section Day and night watch has to be kept, until the flood is over.

It often happens that erosion starts on one of the banks and therefore boat bridge has to be lengthened Two or three boats loaded with planks, beams etc for superstructure are always kept anchored to this bank. As soon as erosion starts, the beams and planks of the first span are removed and a boat is brought in position This is anchored like other boats creating an additional span The beams and planks are placed to form superstructure and roadway. It often happens that the erosion is not sufficient to create the necessity of one more span In that case the boat is brought close to the first boat and anchored The span between the first boat and the new boat is spanned by shorter wooden beams and not by trussed beams

For the boat bridge at Ghazi Ghat, a contingent of about 100 boatmen is sanctioned, who look after the boat bridge as well as the surplus tools and plant kept in the river or creeks

Caulking the joints.

The joints in the boat very often start leaking, and therefore have to be caulked immediately *Oakum* which consists of hessian, or jute fibre soaked with crude oil, is used for the purpose Ordinary cotton can be used for the same purpose, and is generally used by local boatmen who ply country boats A small chisel made of ½ inch diameter rod, with one end flattened out to a sharp edge, is used for caulking *oakum* or cotton into the joint. (See Fig. 15).

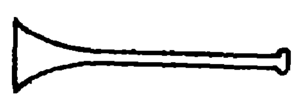


FIG. 15

The joint is cleaned by moving the chisel in it, so that all rubbish, dust, etc , come out of it. *Oakum* thread about 1/16 inch thick is laid over the joints, and pressed in by the chisel. This is further tightened by giving the chisel light blows with a wooden mallet. More *oakum* is added where needed, until the joint is absolutely water-tight. At time of emergency, when a joint cannot be caulked by *oakum*, it is closed by putting a large quantity of earth mixed with clay. This is bad practice, but has often to be resorted to.

Baling out water.

As the depth of water which comes inside a boat is never allowed to exceed two inches, a special tray is used (see Fig. 16) for baling out water. The tray is open at end A, and is dipped in water with bottom AB in horizontal position As soon as water comes into the tray, the end A is slightly lifted and water is thrown out The tray works very efficiently in baling out water

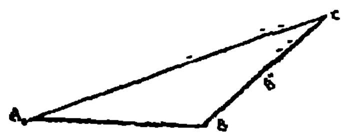


FIG 16

Equipment with each Boatman.

Each boatman is provided with a lantern, a bucket, a tray to bale out water and a chisel and mallet for caulking the joints. In addition to the above, other arrangements for lighting the bridge at the time of emergency are kept at site, which include gas lamps, torches, hurricane lanterns, etc. Life buoys made of cork are also kept, to be used in case of emergency.

Passage of rafts plying the river.

Two days are fixed every week for crossing boats and rafts through the bridge. An advance intimation is sent to the public to avoid delay at the site of the bridge.

The superstructure of two spans and one boat is removed, and boats allowed to pass After the boats have passed, the boat and members of superstructure are brought in position. Usually, that span where water is not too swift, but is sufficiently deep, is selected for the purpose.

Levy of Toll.

All persons and vehicles crossing the bridge have to pay a toll. The toll is collected by the revenue staff who keep a representative at the site. The money collected goes into the coffers of the Provincial Exchequer, and is not considered as a P.W.D. Receipt.

Maintenance of Approach Roads.

As the traffic is rather heavy, and the soil is not too good, the maintenance of approach roads requires constant supervision. The roads are dressed to remove unevenness and sarkanda grass is spread every now and then. On an average, two men are required per mile for maintenance.

Health and Sanitation.

It is the duty of the Ferry Superintendent to see that all his boatmen keep healthy, and premises are kept clean. A first aid box with a medicine chest is kept with him and he administers elementary medicines in case of necessity. The P.W.D. also pay a subsidy for a small dispensary under the charge of a Sub Assistant Surgeon. The dispensary is at a distance of about 6 miles from the boat bridge. All the boatmen receive free treatment in the hospital A shop for provisions is also maintained near the boat bridge, to enable the boatmen to purchase their daily necessities.

Dismantling the Boat Bridge.

The water in the river starts rising in March, and by middle of April part of the approach roads are submerged. The time has come

for dismantling the boat bridge, as winds along with the rise in the river create conditions unfavourable to its safety

The dismantling is started at that end of the river, where the oblique current of water hits the bank. The dismantling will be started at end A (See Fig. 17).

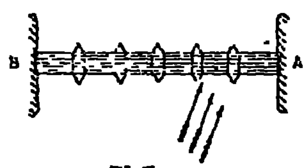


FIG. 17

The first operation is to remove the ballies of hand rails of the entire bridge. After this has been done, planks and trussed beams of first span are removed to a safe place on the bank The roadway planks of the second span are also removed and placed at the two ends of the first boat. The trussed beams are turned over and placed upside down. The first boat is disconnected from the cables, stiffening beams are removed and anchor ropes on both sides are made loose These anchor ropes, however, are still wound on the bows, and are held by boatmen in their hands so that the boat is under control The boatmen go on gradually releasing the anchor ropes as the boat moves Small ropes are tied round the upstream and downstream bows of the first boat, and are held by boatmen in the second boat The trussed beams on both ends are lifted about 6 inches by boatmen The boatmen in the second boat pull at the ropes wound round the bows of the first boat, so that it starts moving. The boatmen in the first boat keep the trussed beams sliding, as this boat approaches the second By the time the first boat has reached the second boat, all trussed beams are loaded centrally over the first boat. All the equipment in the first boat is now placed centrally, anchor ropes are cut away and this boat is taken by the motor launch, or by boatmen to a place of safety.

The advantage of pulling the first boat against oblique current is, that it approaches the second boat slowly In this case also the motion of boat is retarded by the current

The same operation is now repeated with the second and subsequent boats, until the entire bridge is dismantled.

The dismantling of a bridge takes about two or three days It is however essential to remove all boats in swift current the very first day

About 100 men are required for dismantling the boat bridge and taking the equipment to a safe place, and their distribution is practically the same as given in case of erection. There are, however, no ferry boats to drop anchors.

Stabling of Boats during summer.

The boats which have been removed from the boat bridge are anchored to a bank where the current of water is slow These boats are loaded with planks, trussed beams and other members of super-

structure. They are connected in pairs, as stability of a pair of boats is much more than that of single boat and there is little danger of over-turning during floods. The boats are taken to a creek of the river, where velocity of water is low. They are kept anchored to the banks throughout the summer. One boatman per pair of boats is sufficient to look after these.

Warning of floods etc.

A telegraph office is kept open at Ghazi Ghat, and P.W.D. pay subsidy towards its maintenance. Weather forecasts are constantly received, and the Ferry Superintendent is thus made aware of inclement weather, rainfall, and rise in river, well before the time of occurrence. The Irrigation Department maintain a permanent gauge at Attock near Khairabad which is read daily by a gauge reader. The gauge reader communicates the daily gauge at Attock, to the Ferry Superintendent, by a post card. If, however, the rise in river is abnormal, he informs the Executive Engineer and the Ferry Superintendent telegraphically. He is expected to communicate a rise of 5 feet in 24 hours at Attock by wire, so that all precautions are taken by the P.W.D staff for the safety of the boat bridge. It may be stated that water takes about 4 to 5 days in winter and about 3 days in summer to travel from Attock to the site of boat bridge.

From actual observations made during last twenty or thirty years, it has been found that 1 foot rise at Attock raises the level of Indus at Ghazi Ghat as follows:—

Gauge at Attock.	Rise in water at Ghazi Ghat. For one foot rise at Attock.
0 to 10 feet.	0.3 foot.
10 to 15 feet.	0.2 foot.
15 to 25 feet.	0.1 foot.
30 to 40 feet.	0.08 foot.
Above 40 feet.	0.05 foot.

If the gauge at Attock rises from 4 to 9 feet in 24 hours, the actual rise near Ghazi Ghat will be only about 1 5 feet.

Anchors

A brief description of anchors used on the upstream and downstream sides of the boat bridge will be given here. The anchors consist of trangars or netting made of *munj-ban*, containing about 25 cubic feet of boulder stones, and attached to 120 feet long *munj-ropes* which weigh about one maund to one and a quarter maund. The trangars are sometimes made of old and worn out G.I. wire netting which has been discarded from the approach roads. Anchor blocks of concrete, empty tar barrels filled with sand have been tried, but are not very successful. The barrels of tar roll along the bed and therefore anchor ropes become slack The concrete blocks are unwieldy, and very difficult in carriage and handling. They are more expensive than boulders filled in a trangar.

Anchor Ropes of *Munj Ban*.

The *munj-ban* is made from blades which grow with *Sarkanda* reed The blades are beaten with a mallet until they form a very thin fibre. This fibre is twisted to form *Munj Ban* strings

The anchor ropes are about 2½ inches diameter and are made of *munj-ban* thread, about 3/16 inch to ¼ inch in diameter. The anchor ropes are manufactured in rope twisting machine, which consists of two parts (See Plate No. XVII for details).

Part *A* is fixed to the ground, and consists of a driving wheel *D* which rotates a pinion *P* (Fig. 1 & 3). This pinion has bevelled teeth at its periphery and rotates four subsidiary pinions *S* Fig 3

Each subsidiary pinion has a hook made of ½ inch dia rod, which rotates with the pinion.

Part *B* of the machine has wheels at its base; therefore it can slide forward or backward. It also has a driving wheel, which rotates in the opposite direction to that of *A*. At the centre of this driving wheel a hook or ¾ inch dia. rod is fixed, and rotates along with the driving wheel.

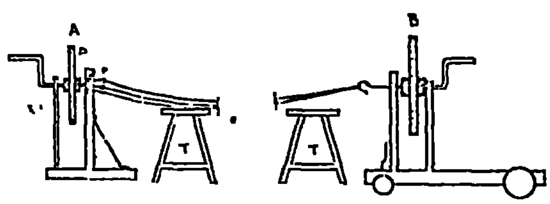


FIG 18

Part *A* and part *B* are placed opposite each other at a distance of about 120 feet as shown in Fig 18 Bundles of *munj-ban* are opened out and the strings are stretched on the ground in the same manner as the weaver spreads warp threads (*Tana*) in his loom. About 6 to 8 of these strings are passed round each hook on the subsidiary pinions of part *A*. There will be thus four sets of these strings, one set round each hook. Each set of strings is held on the other end by a man. Trestles *T*, *T* which are about 2 feet in height are placed at convenient distance apart so that the strings do not touch the ground

The driving wheel of part *A* is rotated, and the strings on each hook wind to form a small rope of about ⅜ inch to ½ inch diameter. The rope starts getting twisted from end *A* and a man walks along the length of strings to see that the twists are gradual, and the strings do not get mixed up Four sets of ropes are made at one time When these small ropes have been formed, all the four ropes are brought on one hook of part *A*. Similarly at the other end these are connected to the hook on the driving wheel of part *B*.

Both the driving wheels are now rotated in opposite direction when these ropes form a secondary rope of ¾ inch dia. When this rope has

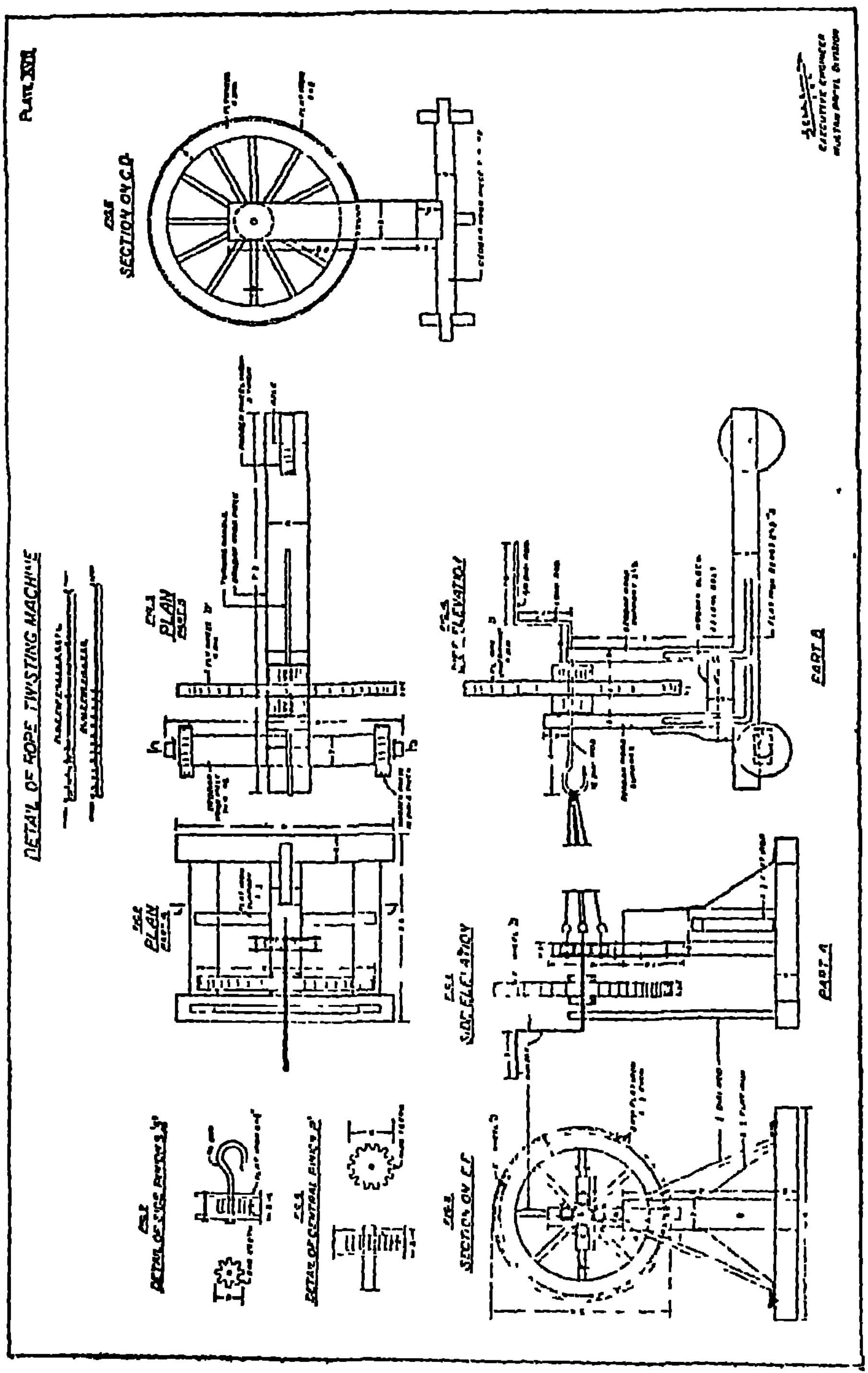


PLATE XVII
DETAIL OF ROPE TWISTING MACHINE
SECTION ON C.D.
PLAN
SIDE ELEVATION
PART A
PART B
SECTION ON E.F.
DETAIL OF SIDE PINIONS
DETAIL OF CENTRAL PINION
EXECUTIVE ENGINEER

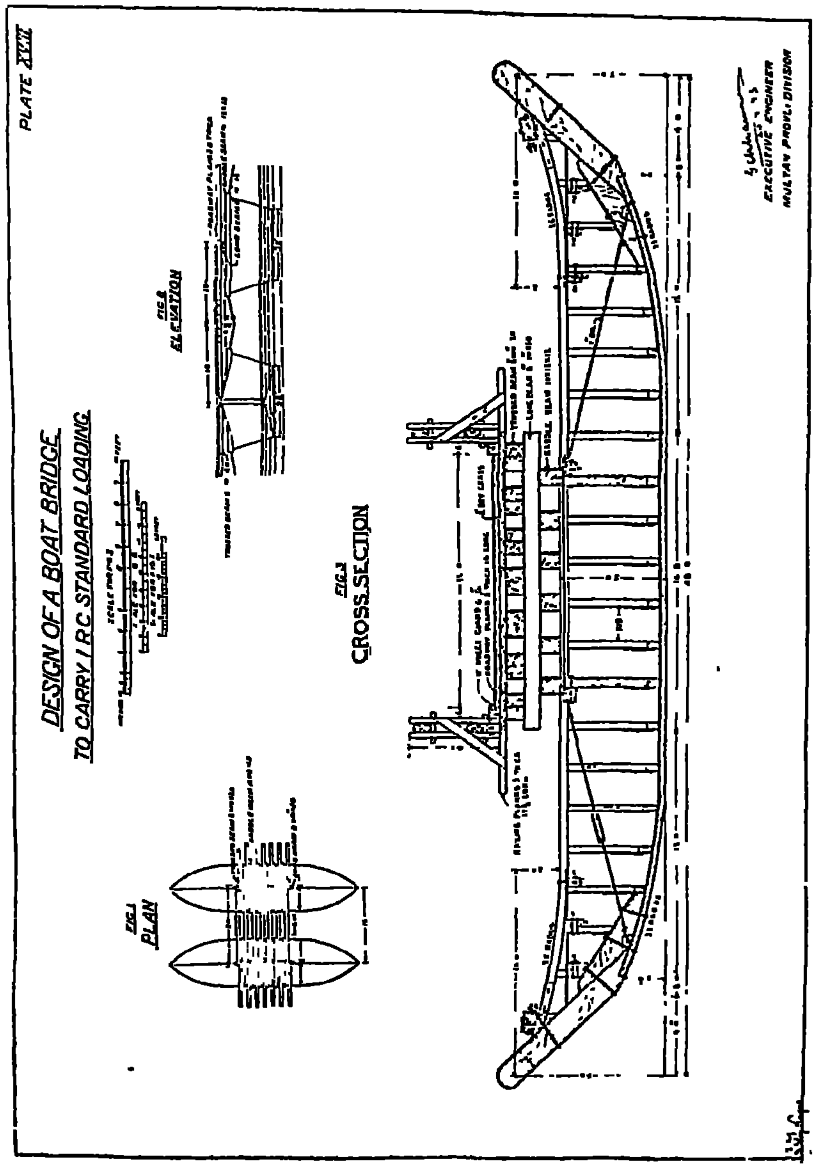


PLATE XVIII
DESIGN OF A BOAT BRIDGE
TO CARRY I.R.C. STANDARD LOADING
FIG.1
PLAN
FIG.2
ELEVATION
FIG.3
CROSS SECTION
EXECUTIVE ENGINEER
MULTAN PROVL: DIVISION

been made, its ends are tied together by *munj-ban* strings as shown in Fig. 19 for a length of about one foot so that it does not get untwisted.

FIG. 19

The secondary ropes are stored at a convenient place until required to form a *munj-ban* anchor.

Four of these secondary ropes make to form one *munj-ban* anchor, which consists about 96 to 100 original *munj-ban* strings. These secondary ropes are connected to one hook on part *A* of the machine and at the other end to hook on part *B* of the machine. In order to keep the twists regular, a four eyed template (See Fig. 20) is used to keep the strings at constant distance apart.

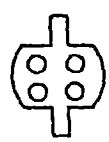


FIG 20

The strings are passed through the four eyed template, and this is moved along the line of ropes from part *A* to part *B*. The driving wheel of part *A* is rotated, and ropes start twisting. The four eyed template comes ahead of the twists, until it reaches part *B* and is then taken out. The machine *B* is then rotated in the opposite direction to machine *A* until the *munj-ban* anchor of required strength and stiffness is manufactured. The ends of anchor rope are tied by *munj-ban* strings and it is then rolled in the form of a helical coil and kept stored until required for use.

G.I. Wire Ropes.

These are more reliable than the *munj-ban* ropes and are preferred in swift current. G.I. wire No. 8 is used for making these and generally six strands of wire are twisted to form a rope. Twisting is done in the same manner as in case of *munj-ban* ropes. The only difference is that two strands of G.I. wire are used at one time for twisting in the machine. When these have been twisted, the double strands are twisted again to form an anchor rope of six strands. The disadvantage of G. I. wire ropes is that they do not stretch. They either get too tight or too loose as the river rises or falls. The *munj-ban* anchors allow a little bit of play, and therefore adjust themselves when the boats rise or fall.

On the upstream side especially in swift water two anchors either of *munj-ban* or G.I. wire are used. A *munj-ban* rope 2 maunds in weight for upstream side has been suggested in the P.W.D. Manual of Orders. This rope is much too thick, and therefore it is preferable to use two separate anchors. Both these anchors are fixed in the same line, that is, the centre line of the boat. It will probably be more advantageous if

they are kept at an angle inclined to the centre line of the boat as shown in fig. 21, so that in case of oblique current one of the two is more helpful. In case of normal currents the resultant of the tension in the two anchors will be in the centre line of the boat. The downstream anchors mainly come into operation when the wind is blowing upstream.

As stated before, the anchors have a few turns round the bows and are tied to these. With the rise of water in the river the boats also rise and therefore a greater length of anchor rope is required. The length can be increased by unwinding one or two turns.

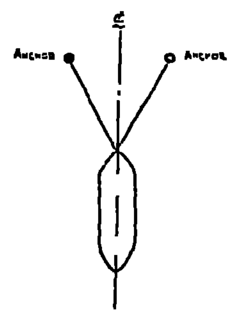


FIG. 21

Life of munj-ban anchors.

The life of *munj-ban* is taken about three months and therefore additional anchors and anchor ropes are added after three months. At time of dismantling the boat bridge, anchor ropes are cut above water level, and the boats are released from the boat bridge.

Waste of material and money.

Every year about 2000 rupees worth of boulders and about 6000 rupees worth of *munj-ban* ropes go down into the river during erection, and maintenance of the boat bridge. This colossal waste cannot be avoided and no means have so far been devised by which the anchor ropes and anchor blocks can be salvaged after the boat bridge has been dismantled.

Steel anchors.

Plate XV shows sketch of a portable steel anchor used for ferry boats, launch etc. It is taken in the motor launch or ferry boat and dropped where necessary.

Construction of a boat

The construction and shaping of a boat is a difficult and intricate job, and is therefore given here in some detail.

Selection of Wood

The wood used for making a boat should be light in weight, easily workable, soft, so that it can be bent into any shape and tough and strong.

Deodar wood is selected for the purpose, as it satisfies all these requirements. The wood should be well seasoned, of best quality, free from sap, cracks, shakes, knots, etc. Long sections are preferable as the number of joints is reduced.

Construction of Hull.

The bottom ribs are laid on the ground at 2 feet intervals and the construction of the hull or bottom of the boat is started. The central key plank which is 12 inches wide and 3 inches thick is laid over the ribs and connected to them by means of dog spikes $1\frac{1}{2}$ inches thick planks are laid on both sides of the key plank. Each $1\frac{1}{2}$ inches plank is about 10 inches to 12 inches wide, and has edges which are true and vertical. The plank is brought close to the key plank and struck by a wooden mallet on its side away from the key plank, so that its joint with the key plank is as narrow as possible. A saw is passed through the whole length of the joint, so that any inequalities on the sides of planks are sawn off. After the joint has been sawn through, the plank is again forced close to the key plank by the wooden mallet. Any inequalities in the joint are again sawn off and the process is repeated until the joint is even and tight. The plank is then connected to the ribs by dog spikes. The next plank is then placed adjacent to this plank and the joint is made tight as explained before. It is then connected to the ribs by dog spikes. Similarly other planks are fixed on the bottom ribs to form the hull of the boat, as shown in Fig. No. 22.

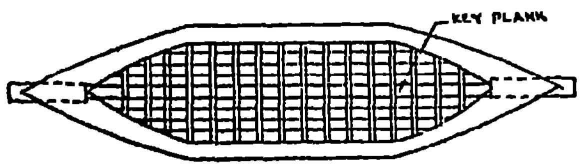


FIG 22

Longitudinal Joints.

The hull of the boat is about 48 feet long and therefore planks must also be connected in the longitudinal direction. A typical plan of scarf joints is shown in Fig. No. 23.

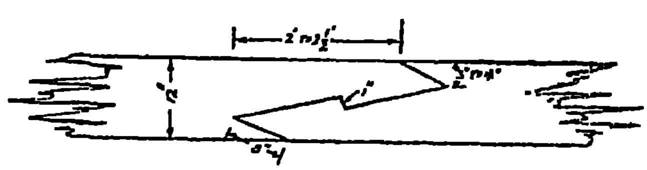


FIG 23

It is imperative that the length of arms of the scarf joint must be at least two feet so that the arms are connected to the ribs at two places at least, otherwise there is danger of the joint breaking loose. These joints should be staggered, so that the strength of the boat is not impaired. When the hull is finally completed, it is painted with two coats of tar. It is then bodily lifted, turned over, so that the ribs are now at top and the hull is at the bottom. It rests on timber scantlings placed on the

ground and does not touch the ground. The hull is horizontal and straight in its central 15 feet length, and is curved at its ends which are about 2 feet higher than the centre In order to achieve this curved shape, the skeleton of the central part of the boat consisting of ribs, gunwale etc is completed. The vertical struts and top gunwale beams are connected to each other to form the skeleton, and then the side ribs are connected to the bottom ribs at the requisite angle. The side ribs are connected to the bottom ribs by mild steel flats and bolts, and to top beams by means of a tenon joint The details are shown in Plate IV. Jacks are placed below the hull at its two ends These ends are lifted gradually by giving a few turns to the jacks. The planks are kept well sprinkled with water, so that they become pliable, and gradually adopt the new shape The process of lifting takes about 4 to 5 hours. The boat is also loaded with stone boulders about 10 maunds in weight, at a place where the curvature in the hull starts This helps bending, as well as giving a smooth curve. When the hull has assumed its true shape, the end beams and the top curved beams are fitted, and the skeleton of the whole boat is completed The ribs at the ends are then fixed in proper position as explained before.

Sides of the Boat

Meanwhile another set of carpenters are busy preparing sides of boats by connecting planks together In connecting the planks to each other some precautions are taken, as described in detail already. The joints should be sawn through until they are absolutly true and tight. The planks are connected to each other by nails made of bamboos These nails are about 3/8 inch dia, and are driven by drilling holes in the plank The hole is drilled at an angle, so that the nail is about 6 inches long as shown in Fig 24.

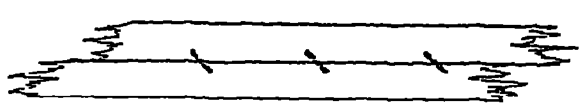


FIG 24

The sides are in one plane for a length of 28 feet in the centre, so there is no difficulty in connecting these planks to the ribs. At the ends, however, these are curved.

The planks are wetted, are forced to their new shape gradually, and the curved parts are connected to the side ribs in a continuous and slow manner Care should be exercised in bending, and no plank should be strained so much, that it gets fractured. The side planks are projecting about 2 inches below the hull The projection reduces the strain on the hull, when the boat runs aground and has to be pulled out It also gives a greater bearing for the nails which connect sides to the hull When the sides have been completed and cut to the exact shape, the tie rods are fitted into the boat and structure is completed. The boat is given three coats of paint before it is lowered in water.

Size of planks.

The planks should be 12 inches to 14 inches in width, and about 20-24 feet in length, so that the boat has a minimum number of joints On account of war this size of planks was impossible to get and therefore smaller planks had to be used. The planks available were 6 inches to 10 inches in width and about 10-12 feet in length. The skilled artisans were averse to using these planks, as these had never been used before. They were very pessimistic about the safety and strength of the boats and were of opinion that it would develop too many leaks The boats made with planks of this size have so far given no trouble. Extra labour was, however, required in making these, and wastage was also greater.

Dog spikes.

The spikes are made locally out of mild steel rods 1/4 inch square in section. Their length is about 5-6 inches. Dog spikes used on key planks are about 10 inches long.

CHAPTER V.

Boat Bridge to carry Indian Roads Congress Standard Loading.

The boat-bridge to carry 8 tons live load has given complete satisfaction in its performance It is proposed now to go a step forward and design a bridge to carry I. R C Standard Loading. A detail design has been worked out in Appendix II, and Plate No. XVIII shows the details of members. The arrangement of members is exactly the same as that adopted for Class VII loading.

A perusal of calculations will show that loads imposed by I R C. Standard Loading are about 50 per cent of loads imposed by Class VII Type vehicle, (See Appendix I), for roadway planks, and about 125 per cent for other members of the superstructure It is not known how I R C. Standard Loading has been derived, therefore it is difficult to explain this discrepancy. Before the publication of Indian Roads Congress Specifications, the load specified for design of highway bridges was based on British Equivalent Standard Loading The B E S. A Loading as adopted in England has an intensity of 15 units, while in India an intensity of 10 units was specified. Calculations have been also worked out with this loading, and it has been found that the 10 units loading imposes loads which are about 100 per cent more than I. R. C. Standard Loading in case of planks, and about 25 percent more in case of other members. To save space these calculations have not been given in the paper.

Size of members.

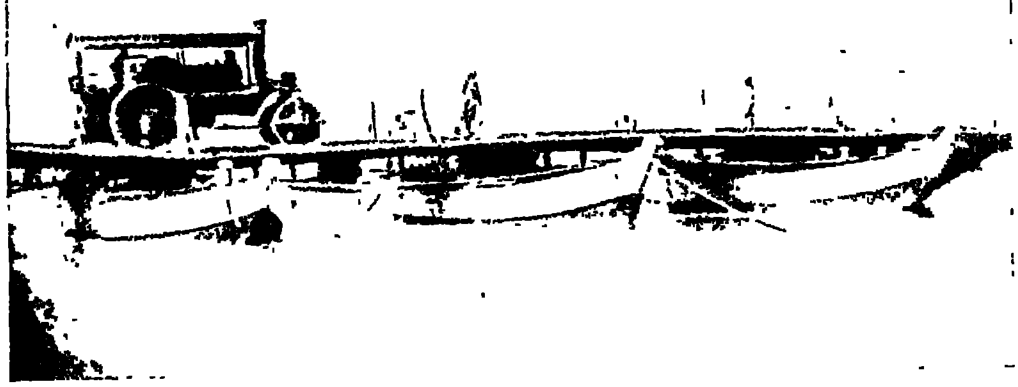
All members are assumed to be made of deodar wood which weighs about 35 lbs. per cubic foot. Working stresses for this timber are given below and have been taken from Indian Forest Records Pamphlet, Volume XVII, page 38 :—

	lbs. per sq in.
Bending	1240
Shear. Horizontal. ..	90
Shear. Along grain ..	130
Compression parallel to grain.	990
Compression perpendicular to grain. ..	295

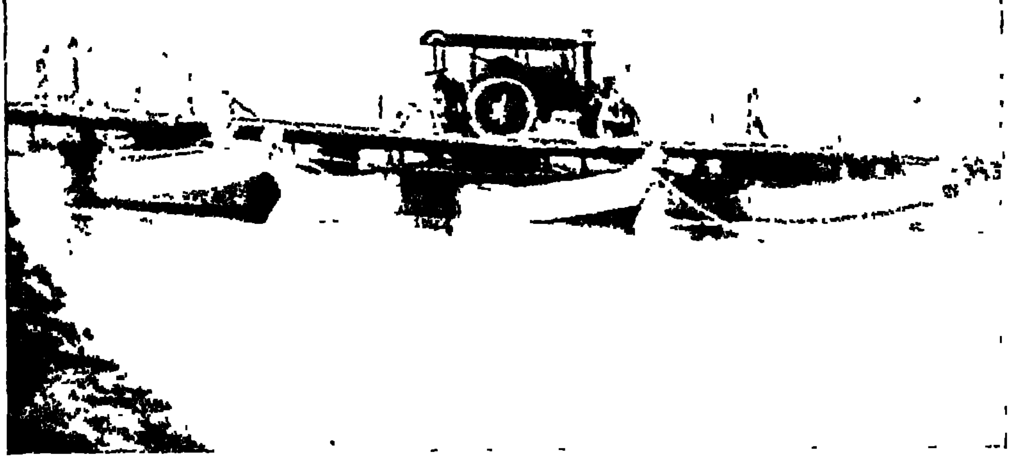
Three inch thick planks are very safe for I. R. C. Standard Loading and are also safe for 10 units B.E S A Loading.

Low stresses have been kept in other members of the superstructure to allow a bigger margin of safety. The compression member of the king post trusses is likely to warp considerably, and thereby cause eccentric stresses. These eccentric stresses will cause heavy bending moments which have not been taken into account in calculations. The stresses allowed are therefore low.

The spacing of boats has been reduced to 20 feet, as trussed beams of 30 feet span will be extremely heavy and difficult to handle It is a



(2) Ten Ton Road Roller crossing a bridge of boats in creeks The roller is on the first boat Mark the deflection in the roadway.



(3) Same as No. 10. The roller is, however, on the second boat.

problem to transport them in carts or lorries on account of their length. The trussed beams of 20 feet span will be lighter in weight and more easy to handle. The dead load on each boat will also be reduced by about 2 tons, and therefore its net buoyancy for heavier loads will be increased. The boat will sink about 12 inches when a live load of this intensity comes over the bridge. This will give a slope of 1 in 20 in the roadway, which may be considered high by some people. Slightly bigger boats may therefore be preferable.

Analysis of costs shows, that for I.R.C. Standard Loading, a span of 25 feet is more economical than a span of 20 feet. The cost of substructure is higher than the cost of superstructure when the span is 20 feet. It may therefore be advantageous to put up a bridge of 25 feet span.

It may be of interest to readers to know that a ten ton road-roller has been passed over the bridge of boats built in a creek of the river. The span was 30 feet. Nine trussed beams instead of seven were used to carry the load. The photographs show the road roller crossing the bridge.

CHAPTER VI

Details of costs.

The details of quantities and costs for a boat bridge and its various parts are given in Appendix III (pages 146,147). The costs per foot run of three different types of boat bridges dealt with in this paper are tabulated below :—

Type of Boat Bridge.	Total Cost per foot run.	Cost per foot run of substructure i.e boats	Cost per foot run of superstructure.
(1) Gunwale Type Boat Bridge with boats at 40 feet centres	Rs. 71/-	Rs. 40/-	Rs. 31/-
(2) Boat Bridge to carry 8 ton live load with boats at 30 feet centres	104/-	54/-	50/-
(3) Boat Bridge to carry I R. C. Standard Loading with boats at 20 feet centres.	143/-	80/-	63/-

The initial costs of a boat bridge of type I and type II, are lower than that of a permanent bridge. The cost of a boat bridge to carry I. R C Standard Loading also compares favourably with the cost of a permanent bridge to carry the same intensity of loading Where heavy training works are to be done, the cost of a permanent bridge may be 50 to 100 per cent more than that of a boat bridge. The analysis of costs shows that the cost of superstructure is practically equal to the cost of substructure This is as it should be, for an economically designed structure It appears from the analysis that the spacing of boats in case of a bridge to carry I. R C Standard Loading can be increased to about 25 feet, so as to get the most economical bridge

In the costs given above, pre-war figures for costs of materials have been taken The cost of timber is Rs. 3/- per cubic foot, and cost of steel including bolts and nuts is Rs 30/- per hundredweight The present day figures keep on fluctuating from day to day, and will be hardly any use for reference purposes

Cost of maintenance.

The cost of maintenance of the boat bridge at Ghazi Ghat including special repairs to boats, and replacement of members of superstructure works out to about Rs. 40,000/- per annum This does not include the cost of running the ferry steamer during summer The cost works out to be about Rs 15/- per foot run per annum As compared to the maintenance cost of a permanent bridge, this cost is extremely high.

ACKNOWLEDGMENTS.

I take this opportunity to express my gratitude to my officers, notably Mr. Trevor Jones, C I E., Chief Engineer, Punjab, P.W.D.; Sir K.G. Mitchell, Consulting Engineer, Government of India; Messrs. J.B. Vesugar and H.A. Harris, Superintending Engineers. These officers took keen interest in the work throughout, guided me in working out designs, and made several useful suggestions.

My thanks are also due to my staff, including Mr. J.P.O. Reilly, Ferry Superintendent, and L Jamna Dass Darogha, who assisted me during the course of the work and made several practical suggestions. They have also helped me in compilation of Chapter IV of this paper on maintenance of Boat Bridge L. Hans Raj Sehgal, Head Draftsman, has helped me in preparation of drawings and other details in the paper.

APPENDIX I.

Design of a Boat Bridge to carry Class VII Type Vehicles. (Or a maximum load of 8 tons).

The arrangement of superstructure beams is shown in Plate No. XI. Fig. No. 3. The planks 3 inches thick, and 12 inches wide are supported on 7 Nos. trussed beams, at 2 feet centres, giving a clear roadway of 12 feet The trussed beams are supported on a single long beam, which in turn is supported on 6 Nos. saddle beams. The saddle beams are supported on gunwales of the boat in such a manner that each saddle beam comes over the ribs of the boat. All the members of superstructure are made of deodar wood, weighing 35 lbs. a cubic foot.

Live Load.

The bridge is designed to carry Class VII Type Vehicles, weighing 7 tons. Including impact, the weight assumed is 8 tons, giving an impact of about 15 per cent. As the speed of the vehicle will not be more than 3 miles an hour, this impact factor is ample.

The front axle will carry $\frac{1}{3}$ the total load .. .. $=2{\cdot}67$ tons

The rear axle will carry $\frac{2}{3}$ the total load .. .. $=5{\cdot}34$ tons.

The distance between axles is 13 feet 2 inches. The vehicle has four wheels at the rear, and two wheels in front.

Weight on one front wheel $=\frac{2{\cdot}67}{2}\times 2240=2990$ lbs

Say $=3000$ lbs.

Weight on one pair of hind wheels $=\frac{5{\cdot}34}{2}\times 2240$ lbs.

Say $=6000$ lbs.

Thus the hind wheels produce the worst effect.

Design of planks.

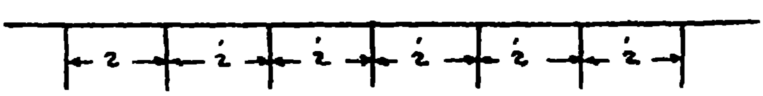


FIG 25

The planks have a span of 2 feet centre to centre

It is assumed that bending moment in end spans $=\frac{WL}{10}$

and

Bending moment in intermediate spans $=\frac{WL}{12}$

The planks are 3 inches thick, and carry 2 inches thick sarkanda grass, saturated with water.

Weight of planks per square foot	$=\frac{1}{4}\times 35=9$ lbs.
Weight of sarkanda grass	$=\frac{1}{6}\times 35=6$ lbs
Total dead load per square foot	$=$ 15 lbs.
B.M. due to dead load $=\frac{15\times 2^2}{10}$	$=6$ ft. lbs. (Negligible)

Live Load.

Each pair of hind wheels carries a load of 6000 lbs. distributed in a width of 1 foot and 3 inches below the tyres.

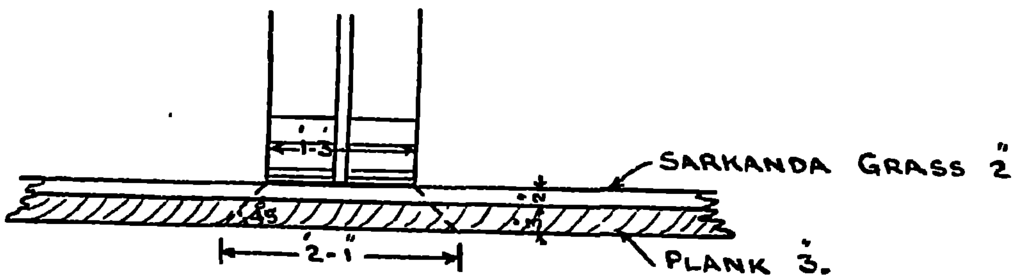


Fig 26

Assume a dispersion of 45 degrees, and this load may be considered distributed in a width of $(1'\text{-}3''+2\times 5'')=2'\text{-}1''$

Say $=2'-0''$

Bending moment due to live load in end span $=\frac{6000\times 2\times 12}{10}$

$=14400$ inch lbs

For planks 12 in. by 3 in. $I=\frac{bd^3}{12}=\frac{12\times 3^3}{12}=27$ in^4

$F=\frac{M}{I}Y.=\frac{14400}{27}\times 1{\cdot}5=800$ lbs. per square inch which is safe

Or using formula given on pages 21-22 of I R. C. Bridge* Specifications we get

$$M=\frac{p}{8}bd^2 \text{ or } 14400 = 207\ bd^2,\ (p=1653.)$$

$$\text{If } b=12 \text{ inches; } d=\sqrt{\frac{1200}{207}}=2.4 \text{ inches.}$$

*Standard Specification and code of practice for Road Bridges in India—I.R.C. 1937.

Shear.

Due to dead load $= \frac{15 \times 2}{2}$ $= 15$ lbs.

Due to live load $= \frac{6000}{2}$ $= 3000$ lbs.

Total. $= 3015$ lbs.

Shear stress. $= \frac{3015}{12 \times 3}$

$= 83$ lbs per sq. inch.

Design of King post Trusses. (See plate XI)

There are seven trusses carrying the roadway.

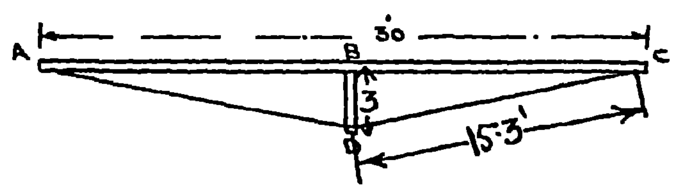


Fig 27

Dead load per foot run of roadway	$=14 \times 15 = 210$ lbs	
Weight of hand rails etc.	$=2 \times 20 = 40$ lbs.	
Total.	$= 250$ lbs.	

Note.

The hand rails consist of two ballies which weigh about 10 lbs. per foot run. The load of hand rails will come on two trussed beams placed outside, but for simplicity of calculation this load has been assumed to be distributed on all the trussed beams.

Weight per foot run on each truss $= \frac{250}{7}$ $= 36$ lbs.

Weight of truss per foot run is calculated below :—

$7'' \times 10''$ pieces 30 feet long	$= \frac{70}{144} \times 35 \times 30$	$= 510$ lbs.
Weight of $1\frac{1}{2}$ inch ϕ tie rod	$= 31 \times 3.38$	$= 105$ lbs
Side pieces 2 Nos $3'' \times 10''$, 8 feet long	$= \frac{60}{144} \times 8 \times 35$	$= 117$ lbs
Shisham prop $4\frac{1}{2}$ in by 13 in. by 2.6 at the centre at 49 lbs per cu ft	$= \frac{2.6 \times 4.5 \times 13 \times 49}{144}$	$= 52$ lbs.
$\frac{3}{4}''\phi$ bolts 14" long 12 Nos	$= 12 \times 2.3$	$= 28$ lbs
Bearing plates at ends 2 Nos.		$= 20$ lbs.
Angle irons at junction etc.		$= 10$ lbs.
	Total	$= 842$ lbs

Weight per foot run of each truss $= \frac{842}{30}$ $=28$ lbs.

Dead load per foot run $=36+28$ $=64$ lbs.

Dead load stresses.

Reaction at B. (Fig. 27) $=2\times\frac{5}{8}\, wl$

$=2\times\frac{5}{8}\times 64\times 15$ $=1200$ lbs

B.M. at B. $=(\frac{1}{8}\, wl^2)$ negative.

$=-\frac{1}{8}\times 64\times 15^2$ $=-1800$ ft. lbs.

Maximum positive B.M.

at a point 0 375 L from end $=(\frac{9}{128}wl^2)$

$=\frac{9}{128}\times 64\times 15^2$ $=1010$ ft. lbs.

Note : The constants of bending moments have been taken from Concrete Plain and Reinforced by Taylor and Thomson Vol. II (1938 Edition), pages 34-36.

Live load stresses.

Page 55 of M.E.S. Hand Book Vol. III (Roads) (Reprint 1930) gives the following formula for distribution of bending moments from roller on stringers :—

B.M. on one stringer $= \frac{\text{B.M. due to roller} \times \text{spacing of stringer.}}{8}$

In this case spacing $=$ 2 feet.

Therefore bending moment or load on each stringer $=25$ per cent.

Concentrated load on each stringer due to hind wheels $=2\times 6000\times\frac{25}{100}$

$=3000$ lbs.

Concentrated load due to front axle $=2\times 3000\times\frac{25}{100}$

$=1500$ lbs.

Maximum negative moment at B due to hind wheels. $=(1-C_{10})pl$

The maximum value of C_{10} is 0.097 or 0.1 (vide p 36 Concrete Plain and Reinforced by Taylor Thompson and Smulsky.) (1938 Edition)

With P=3000 lbs. and L=15 ft, max. negative B. M. .. .. .. $=0{\cdot}1\times 3000\times 15$ ft. lbs.

$=4500$ ft. lbs.

The front wheel will also produce a negative moment at B. The maximum value of co-efficient C_{10} will be 0.08.

Hence B.M. $=1500\times 15\times 0{\cdot}08$

$=1800$ ft. lbs.

Negative B.M. due to both loads $= 4500 + 1800$ ft. lbs
$= 6300$ ft. lbs

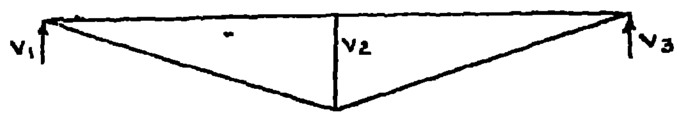


Fig 28

Values of shear due to front wheel loads are :—

V_1	$= 0{\cdot}4 \times 1500$	$= 600$ lbs.
V_{2l}	$= (1-0\ 1)\times 1500$	$= 900$,,
V_{2r}	$= 0\ 08 \times 1500$	$= 120$,,
V_3	$= -0\ 08 \times 1500$	$= -120$,,

Values of shear due to hind wheel loads are :—

V_1	$= -0\ 1 \times 3000$	$= -300$ lbs.
V_{2l}	$= 0\ 1 \times 3000$	$= +300$,,
V_{2r}	$= (1-0\ 3)\times 3000$	$= +2100$,,
V_3	$= 0\ 3 \times 3000$	$= +900$,,

Thus total shear due to both the loads are —

V_1	$= 600 - 300$	$= 300$ lbs
V_{2l}	$= 900 + 300$	$= 1200$ lbs.
V_{2r}	$= 120 + 2100$	$= 2220$ lbs.
V_3	$= -120 + 900$	$= 780$ lbs.

The total reaction at central prop. $V_{2l} + V_{2r} = 3420$ lbs.

Maximum positive moment will occur at the centre of span when hind wheel is over it.

Maximum bending moment $= C_0\, P_a$
Where P $= 3000$ lbs.
a $= 0\ 5L$ and $C_0 = 0\ 42$
$= 0{\cdot}42 \times 3000 \times 0\ 5 \times 15$
$= 9450$ ft lbs.

If the front wheel is on the truss also, the effect of this would be to reduce this B M. We will assume that this wheel is on the other truss, so as to get worst condition.

Thus negative moment at B $= 6300 + 1800$ ft lbs.
$= 8100$ ft lbs.

and maximum positive moment in span $= 9450 + 1010$ ft lbs.
or say $= 10500$ ft. lbs.

Maximum vertical shear at B due to dead load $= 1200$ lbs.
Maximum vertical shear at B due to live load $= 3420$ lbs

Total shear $= 4620$ lbs.

Determination of size of members.

The strut will be 12 inches wide and $4\frac{1}{2}$ inches thick.

Direct compression $= \frac{4620}{12 \times 0{\cdot}45} =$ 86 lbs per square inch.

Bearing stress on top members $= \frac{4620}{7 \times 4\frac{1}{2}} =$ 150 lbs. per square inch.

Bearing of $1\frac{1}{8}''$ dia rod $= \frac{4620}{1{\cdot}125 \times 4{\cdot}5} =$ 913 lbs. per square inch.

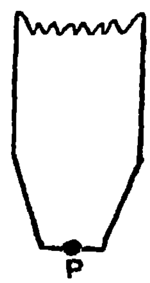


Fig 29

The bottom of strut will have $4\frac{1}{2}'' \times \frac{1}{4}''$ plate at bottom which will distribute the vertical stress due to rod. over a big area and thus reduce the local stress at point P.

Tension in AD and CD due to dead and live load. (Fig. 27) .. $= \frac{4620 \times 15{\cdot}3}{2 \times 3} =$ 11800 lbs.

Use $1\frac{1}{8}$ inch dia. rods for tie rods.

As the tie rods have threads at their ends, net dia. of rod will be 1 inch.

Stress in tie rod $= \frac{11800}{0{\cdot}785}$

$=$ 15000 lbs. per square inch.

Member AB and BC

Direct stress due to dead and live loads $= \frac{4620 \times 15}{2 \times 3} =$ 11550 lbs.

Maximum positive B. M. $=$ 10500 ft. lbs. or 126000 in. lbs.

Maximum negative B.M. $=$ 8100 ft. lbs. or 97200 in. lbs.

$$f_c \text{ or } f_t = \frac{P}{A} \pm \frac{MY}{I}$$

$$= \frac{11550}{7 \times 10} \pm \frac{126000 \times 5 \times 12}{7 \times 10 \times 10 \times 10}$$

$= 165 \pm 1080$ lbs. per Sq. in.

$=$ 1245 or 915 lbs. per sq. in.

Design at Joint B.

As there are splices, compression stress is safe,

$$f_c \text{ or } f_t = \frac{11500}{13\times10} \pm \frac{97200\times6}{2\times3\times10^2}$$

$$=88\pm972 \text{ lbs. per Sq. in.}$$

Tension $=884$ lbs per square inch.

The stresses in the different members of the Truss are all within permissible limits

Design of long beam.

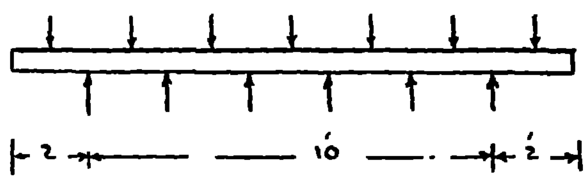


Fig 30

The long beam is supported on saddle beams 2 feet centres This beam has 5 spans of 2 feet and cantilevers 2 feet on each side.

In each span the trussed beams rest and impose a concentrated load.

Load on each span due to dead load $=30\times64 = 1920$ lbs

Live load.

When the hind wheel is just over the end of truss the maximum load is produced

Maximum load $= 3000+(1500\times\frac{16\ 84}{30})$

$= 3000+842$ lbs.

or say $=3850$ lbs.

The second term in the above expression is due to the front wheel, (wheel base 13 ft 2 in.).

Total dead and live load in span $=3850+1920 = 5770$ lbs.

B M in span $=\frac{WL}{5}=\frac{5770\times2}{5}=2308$ feet lbs

B M. in cantilever .. $=5770\times1\ 3$ $=7500$ feet lbs.

$=90,000$ in lbs.

Note. This condition will never arise, as the hind wheel can never reach upto the wheel guard

Assume 8″×8″ Section. $I=\frac{1024}{3}$; $Y=4$; $Z=\frac{I}{Y}=\frac{256}{3}$

Therefore $f=\frac{MY}{I}=\frac{90,000\times3}{256}$

$=1055$ lbs. per square inch.

Shear $=\frac{5770}{64}=90$ lbs. per square inch.

These stresses are within safe limits.

Design of saddle beams.

Span of saddle beam	..	= 12 feet.
These beams are six in number.		
Dead load for superstructure (Trusses)		$=64\times30\times7$
		=13440 lbs.
Add weight of long beam, 8″×8″×14′		= 220 lbs.
Total dead load		=13660 lbs.
Live load	$=8\times2240$	= 17920 lbs.
		31580 lbs.

Load on each beam $=\frac{31580}{6}=5260$ lbs.

Assume 10″ wide and 10″ high section.

Its weight per foot run. .. .. = 25 lbs.

B.M. due to concentrated load $=\frac{5260\times12}{4}=15780$ ft. lbs.

Due to its own weight $=\frac{25\times12^2}{8}=450$ ft. lbs.

Total B.M. $=15780+450=16230$ ft. lbs

$=1,94,760$ in. lbs.

Section modulus $Z=\frac{1}{6}bd^2$ in^3.

$=\frac{1}{6}10\times10\times10=\frac{1000}{6}$in^3.

$f=\frac{M}{Z}=\frac{194760\times6}{1000}$

$=1169$ lbs. per sq. in.

This is safe.

Design of Boat.

The saddle beams are supported on the gunwales which transmit the load to the ribs etc The size of gunwales of boat is 10 inches by 4 inches

Load on gunwale from each saddle beam $= \frac{5260}{2} + \frac{25 \times 12}{2} = 2780$ lbs

This load acts directly on ribs, which are 6 inches by 3 inches.

Direct stress in ribs $= \frac{2780}{6 \times 3} = 154$ lbs per square inch, which is safe.

If however these beams are placed in position at the centre of ribs, then maximum shear in gunwales

$$= \frac{2780}{2} = 1390 \text{ lbs}$$

Shear stress $= \frac{1390}{36} = 39$ lbs per square inch.

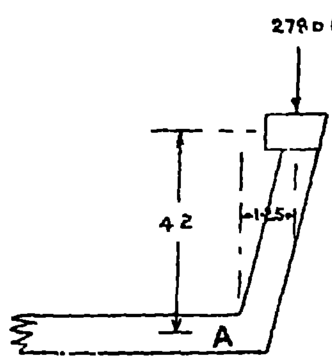
B M $= \frac{2780 \times 2}{5} = 1100$ ft lbs $= 13200$ in lbs

$$Z = \frac{10 \times 4 \times 4}{6} = \frac{160}{6} \text{in}^3.$$

$$f = \frac{13200 \times 6}{160}$$

$= 495$ lbs per sq in. which is safe.

Fig 31



It will be seen that the load on the ribs is central at top, but eccentric at bottom, as the rib is built inclined. The total vertical load on each rib is 2780 lbs.

Load on all the six ribs $= 2780 \times 6 = 16680$ lbs.

By taking moments about point 'A', tension in the rods which are parallel to the saddle beams is obtained.—

$$T \times 4.2 = 16680 \times 1.25$$

$$T = \frac{16680 \times 1.25}{4.2} = 5000 \text{ lbs}$$

There are two tie rods, therefore tension in each $= \frac{5000}{2} = 2500$ lbs.

The tie rods are 3/4 inch diameter, and are fitted with bolts at each end

The net area of tie rod will be $= \frac{\pi}{4} \times \left(\frac{5}{8}\right)^2$

$= 0.3$ square inch.

Hence stress in tie rods $= \frac{2500}{0.3}$ lbs. per sq. inch.

$= 8333$ lbs. per square inch, which is safe.

Thus the two 3/4 inch tie rods are ample

Now consider the strength of boat when it is resting on sand.

The total load of super-structure,
live load, boats etc. $= 12 \times 2780 + 6.5 \times 2240$ lbs
$= 33360 + 14560 = 47920$ lbs

When the boat is resting
on sand the bearing area $= 14.67 \times 9.5$ sq feet.
$= 139$ sq. feet

Hence total load per square foot $= 345$ lbs.

This figure will only hold, if the sand surface were absolutely rigid like a concrete pavement. When the boat touches the soft sand, it will be definitely buried in sand with water pressure all round.

Even if the boat sinks about 3 inches in sand, the bearing area is considerably increased with corresponding reduced stresses.

The bottom planks are $1\frac{3}{4}$ inches thick and have a span of 2 feet.

Load on planks $=$ 345 lbs. per sq. ft.

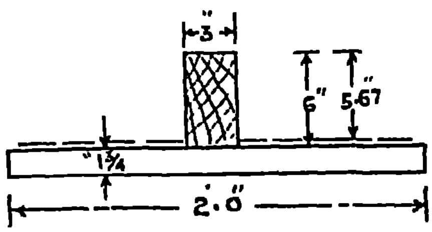
Hence B.M. $= \frac{345 \times 2^2}{10} = 138$ ft. lbs. or 1656 in. lbs.

$$Z = \frac{1}{6} \times 12 \times 1.75^2 = 6.125 \text{ in.}^3.$$

$$f = \frac{M}{Z} = \frac{1656}{6.125} = 270{\cdot}4 \text{ lbs per sq. in. which is safe.}$$

Now consider the design of ribs.

Fig. 32.



The ribs and bottom planks may be considered as acting together as a composite section

C. G of section from top $= \dfrac{2\times12\times1.75\times0.875 + 6\times3\times3}{2\times12\times1.75 + 6\times3}$

$= 5.67$ inches

Moment of Inertia $= \dfrac{1}{12}\times24\times(1.75)^3+42(0.875+0.33)^2+$

$\dfrac{3}{3}\times(5.67)^3 + \dfrac{3}{3}(0.33)^3$.

$= 5.36+60.98+182.28+.04$ in.^{4}

$= 248.56$ in.^{4}

Weight of rib and bottom planks acting downwards $= \dfrac{60}{144}\times35 = 15$ lbs

Net upward pressure $= (2\times345-15) = 675$ lbs per Rft

B.M. on rib $= \dfrac{675\times9}{10}\times12$ in. lbs.

$= 65610$ inch lbs.

Maximum stress $= \dfrac{65610\times5.67}{248.56}$

$= 1515$ lbs per square inch

This stress is slightly higher than permissible.

Factor of safety $= \dfrac{87000}{1515} = 6$ Say.

Maximum shear at ends $= \dfrac{675\times9}{2} = 3037.5$ lbs.

Shear stress $= \dfrac{3037.5}{3\times7.75}$ lbs. per square inch

$= 131$ lbs per square inch.

This is slightly higher than the permissible stress which is 100 lbs per square inch. In the new boats, ribs at the centre have been increased to 7″×4″ in size and therefore stresses will be reduced. In old boats ribs have been strengthened by adding a 6″×3″ rib by the side of each rib.

Now consider the effect of water pressure on boat.

The boats are to be submerged about 2.5 feet in water.

Pressure per square foot $=62.5\times\frac{5}{2}=156$ lbs.

This pressure is lower than that when the boat rests on sand. Hence the ribs and planks are safe.

When the boats are sumberged 2 5 feet in water, there will be side pressure on boats equal to $=\frac{62.5\times2.5}{2}\times 2\ 5$

$=200$ lbs. per foot run.

This will be acting at a distance $\frac{(2.5)}{3}$

$=0\ 833$ foot from bottom.

There are two struts at top in a distance of 20 feet.

Total pressure in 20 feet distance$=200\times20=4000$ lbs.

This will be divided in the proportion of 0.6 to 4.2 in top and bottom struts.

The top struts will take $\frac{(4000\times0.6)}{4.8}$

$=500$ lbs.

Each strut will carry $\frac{(500)}{24}=24$ lbs. per square inch, which is safe.

Design of Anchors.

The horizontal forces acting on the boat bridge are wind pressure, and pressure exerted by water. These pressures have been calculaed by using the formula given in I.R C Bridge Specifications, pages 10-12.

Wind pressure per span.

Area of boat above water $= 3.5\times\frac{12+10}{2}$ = 38.5 Square feet.

Area of saddle beams exposed to wind. $= 13\times\frac{10}{12}$ = 11.0 Square feet.

Area of long beams	$= \frac{8}{12} \times \frac{8}{12}$	= 0 4 Square feet.
Area of trussed beams		= 30 Square feet.
Area of roadway planks and sarkanda grass	$= 30 \times \frac{1}{3}$	= 10 Square feet.
Total area.		= 90 0 Square feet
Wind pressure with no live load	$= 50 \times 90$	= 4500 lbs
With live load of 5 ton lorry the exposed area, (as the boat gets submerged)	= (90—10)	= 80 Square feet

The length of lorry is assumed to be 16 feet.

Wind pressure with live load $= 80 \times 20^{*} + 200^{\dagger} \times 16 = 4800$ lbs.

Pressure of water on boat is given by the formula —

$$P = KA^{*}V^{2}$$

Where $K = 0.46$ (as boat has cut waters)

A = Area of boat immersed

$$= 2.5 \times \frac{9\ 5 + 10.75}{2} = 26 \text{ Square feet}$$

V = 10 feet per second.

pressure $= 0\ 46 \times 26 \times 10^{2} = 1200$ lbs

Thus the total pressure which is exerted on the anchor is :

Wind pressure	= 4800 lbs.
Water pressure	= 1200 lbs.
Total	= 6000 lbs.
or say	= 3 tons

The breaking strength of G. I. wire anchors is about 3 tons Two anchors are used in swift water giving a factor of safety of 2 only. The breaking strength of munj-ban anchors is about 1 to $1\frac{1}{2}$ tons. Munj-ban anchors are therefore unsafe in case of severe windstorms. As the boat bridge is dismantled in middle of April, it is not subject to severe forces due to windstorms or strong current of water.

Design of Chain or Wire Rope Cables.

The chain will come into action when the anchor rope of a boat gets broken Supposing one boat gets loose, it will exert a pressure of 3 tons on the chain The stress in the chain will depend on the deflection in the chain If the chain is too tight and is built straight from end to end, the stresses will be high. If the chain is loose, and can deflect, then the stress in it will be low.

† Standard specification and code of practice for road bridges in India page 11.
* do. do. do do. do. do. page 12.

Assume that both the upstream and downstream chains deflect 2 feet as shown in sketch

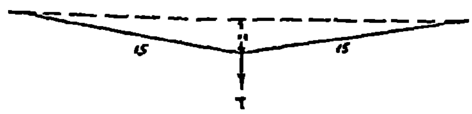


Fig 33

Tension in strings $= T = \frac{15}{2} W = 7 \cdot 5\ W.$

As half the load is taken by upstream cable and half by downstream cable,

tension $= 7 \cdot 5 \frac{W}{2} = 7\ 5 \times 1 \cdot 5 = 11\ 25$ tons

This is safe for G. I. wire rope of 4 inches girth, but unsafe for $\frac{3}{4}$ inch diameter chain which has a safe stress of 8 tons Two chains are used on the upstream side in swift water. So far chains have never broken, therefore it seems that constants for wind pressure and water pressure are too high.

APPENDIX II.

Design of a Boat Bridge to carry I.R.C. Standard Loading.

The design calculations are on the same basis as given in Appendix I

The arrangement of superstructure beams, planks, etc., is shown in Plate No XVIII The planks are supported on 7 trussed beams at 2 feet centres giving a clear roadway of 12 feet The trusses are supported on a single long beam which in turn is supported on 6 saddle beams. The saddle beams are supported on gunwales of the boat in such a manner that each saddle beam comes over the ribs of the boats. All the members of superstructure are made of deodar wood.

Live load.

The bridge is designed to carry I R C Standard Loading. As the speed of vehicles over the boat bridge will be restricted to 3 miles per hour, an impact factor of 15 per cent will be more than ample.

Design of planks.

The planks have a span of 2 feet centre to centre It is assumed that bending moment in end spans $=\frac{WL}{10}$, and intermediate spans $=\frac{WL}{12}$.

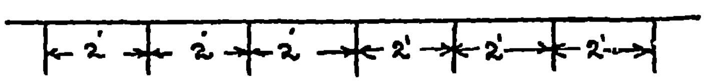


Fig 34.

The planks are 3 inches thick and carry 2 inches thick sarkanda grass

Weight of planks per square foot $=\frac{1}{4}\times 35 = 9$ lbs.

Weight of sarkanda grass per square foot $=\frac{1}{6}\times 35 = 6$ lbs.

Total dead load per foot run $= 15$ lbs.

B. M due to dead load $=\frac{15\times 2^2}{10} = 6$ ft. lbs.

Live Load.

B.M due to distributed load including impact $=\frac{0.68\times 2240\times 1.15\times 2}{10} = 350$ ft. lbs.

B.M. due to knife edge load $=\frac{0.6\times 2240\times 1.15\times 2}{10} = 308$ ft lbs.

Total B M. $= 6+350+308 = 664$ ft. lbs.

$= 7968$ in lbs.

I = Moment of inertia of planks $= \frac{bd^3}{12} = 27$ in.^{4}

$f = \frac{MY}{I} = \frac{7968}{27} \times 1.5$ = 442 lbs per square inch

which is safe.

Or using formula given on pages 21-22 of I.R C. Bridge Specifications we get—

$$M = \left(\frac{p}{8} bd^2\right)$$

Where 'p' for Deodar is 1653

$$\therefore d = \sqrt{\frac{8M}{pb}} = \sqrt{\frac{8 \times 7968}{1653 \times 12}} = 1.8 \text{ inches.}$$

Shear.

Due to dead load $= \frac{15 \times 2}{2} = 15$ lbs.

Distributed live load $= \frac{0.034 \times 2240 \times 1\ 15 \times 2}{2} = 88$ lbs

Due to concentrated load $= \frac{9 \times 2240 \times 1.15}{10} = 2310$ lbs.

Total shear $= (2310 + 88 + 15) = 2413$ lbs.

2 inches thick planks give

a shear of $\frac{2413}{2 \times 12}$ = 100 lbs. per square inch

which is safe.

Design of Trusses.

The trusses have a span of 20 feet.

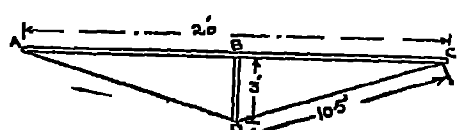


Fig 35

There are seven trusses carrying the roadway, therefore dead load per foot run of roadway .. .. = 14 × 15 = 210 lbs.

Add for hand rails, etc. .. .. = 2 × 20 = 40 lbs.

Total .. 250 lbs.

Note :—The hand rails consist of two ballies which weigh about 10 lbs. per foot run. The weight of these will come on the two trussed beams placed outside but for simplicity of calculation this load has been assumed to be distributed in all the trussed beams.

Weight per foot on each truss $= \frac{250}{7} = 36$ lbs

Weight of truss per foot run (See page 145) = 36 lbs

Total dead weight per foot run .. = 72 lbs.

*** Dead load stresses**

Reaction at B .. .. $= \frac{5}{8} \times 72 \times 20 = 900$ lbs.

Tension in AD and CD (Fig. 35) .. $= \frac{900}{2} \times \frac{10 \cdot 5}{3}$ or 1600 lbs.

Compression in AB and BC (Fig. 35).. $= \frac{900}{2} \times \frac{10}{3} = 1500$ lbs.

B.M at B $= (-\frac{1}{8} wl^2)$ Negative
$= \frac{1}{8} \times 72 \times 10^2 \times 12$ or 10800 inch lbs.

Maximum positive B M at a point
0 375 L from end .. .. $= \frac{9}{128} wl.^2$
$= \frac{9}{128} \times 72 \times 10^2 \times 12 = 6072$ inch lbs.

Live Load stresses :

Distributed live load per foot run
including 15 percent impact $= \frac{0\ 34 \times 2240 \times 1.15}{7}$ lbs. $=$ 125 lbs.

Knife edge load for B.M $= \frac{6 \times 1.15 \times 2240}{7}$ lbs. $= 2200$ lbs.

Knife edge load for shear $= \frac{9 \times 1\ 15 \times 2240}{7}$ lbs. $= 3300$ lbs.

B.M. due to distributed live load at B $= \frac{1}{8} \times 125 \times 10^2$
$= 1560$ ft. lbs. (negative)

Positive moment at point 0.375 L $= \frac{9}{128} \times 125 \times 10^2 = 860$ ft. lbs.

Moment due to knife edge load :

Positive Moment $= 2200 \times \frac{10}{2} \times 0.42 = 4600$ ft. lbs.

Negative Moment $= \frac{2200 \times 10}{10} = 2200$ lbs.

Hence maximum negative
moment at point B $= (900 + 1560 + 2200) = 4660$ ft. lbs

Maximum positive moment $= (506 + 860 + 4600) = 5966$ ft lbs.
say $= 6000$ ft. lbs.

* The constants of bending moments have been taken from Taylor and Thompson's Book on Reinforced Concrete, Volume II, pages 34-36.

Maximum vertical shear.

At point B the shear is :—

Distributed live load	$=125\times20\times\frac{5}{8}$ lbs. $=1560$ lbs.
Knife edge load shear	$=3300$ lbs.
Due to dead load	$=900$ lbs.
Total	$=5760$ lbs.

Determination of size of members.

The strut will be 12″ wide and $4\frac{1}{2}$ inches thick.

Direct compression $=\frac{5760}{12\times4\cdot5}$ lbs. per sq. inch.

$=110$ lbs per square inch

Bearing stress on top piece $=\frac{5760}{8\times4\frac{1}{2}}$

$=160$ lbs. per square inch.

Bearing of $1\frac{1}{8}$″ dia rod $=\frac{5760}{1\cdot125\times4\cdot5}$

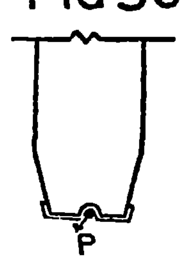
$=1118$ lbs. per square inch.

The bottom of strut will have $4\frac{1}{2}$″ by $\frac{1}{4}$ inch plate at bottom which will distribute the vertical stress due to rod over a big area, and thus reduce the local stress at point P.

Tension in AD and CD due to dead and live load. (See Fig. 35.) $=\frac{5760\times10\cdot5}{3\times2}=10000$ lbs.

Use $1\frac{1}{8}$″ϕ rods. As there will be threads at each end, the ends will be reduced to 1″ϕ.

FIG 36



Stress in rod $=\frac{10000}{0\cdot78}=13000$ lbs. per sq. inch.

Member AB and BC.

Direct stress due to dead and live loads. (See fig. 35.)	$=\frac{5760\times 10}{3}=19200$ lbs
Maximum positive B.M.	$=6000$ ft. lbs or 72000 in. lbs.
Maximum negative B.M.	$=4660$ ft. lbs. or 55920 in. lbs.
f_c or f_t	$=\frac{19200}{8\times 10}\pm\frac{72000\times 6}{8\times 10^2}$
	$=240\pm 540$ lbs per. sq. inch.
	$=780$ lbs. or 300 per sq inch

A low stress has been allowed as it has been found that these members warp considerably.

Design at Joint B.

There is a maximum negative moment at this point of 4660 ft lbs only. $3''\times 10''$ plates will be ample to take up the stress.

Tension at Joint	$=\frac{19200}{14\times 10}-\frac{55920\times 6}{6\times 10^2}$
	$=138-560$
	$=-422$ lbs per square inch

The stresses in all the members are thus safe.

Design of long beams.

The long beam is supported on saddle beams at 2 feet centres This beam has 5 spans of 2 feet and cantilevers 2 feet on each side

The trussed beams rest in each span and impose a concentrated load.

Dead load	$=\frac{2\times 72\times 20}{2}$	$=1440$ lbs.
Live load distributed	$=\frac{6{\cdot}8\times 2240\times 1{\cdot}15}{7}$	$=2500$ lbs.
Live load concentrated	$=\frac{6\times 2240\times 1\ 15}{7}$	$=2200$ lbs.
Total dead and live load	$=(1440+2500+2200)$	$=6140$ lbs
B. M. at centre of span	$=\frac{6140\times 2}{5}$	$=2456$ ft lbs
B M. due to cantilever	$=6140\times 1{\cdot}3$	$=8000$ ft. lbs

The outside trussed beam is at a maximum distance of 1 3 feet.

Hence stress $=\dfrac{8000\times 12\times 5}{8\times\frac{10^2}{12}}=720$ lbs per sq in.

Maximum shear $= 1440 + 2500 + 3300$ lbs. $= 7240$ lbs.

Shear stress $= \frac{7240}{80} = 90$ lbs per sq. inch which is safe.

Saddle beams.

There are 6 beams and their span is 12 feet

Dead load from superstructure $= 72 \times 7 \times 20$ lbs. $= 10080$ lbs.

Add weight of $8'' \times 10'' \times 14'$ beam $=$ 280 lbs.

10360 lbs.

Weight of live load $= (6 + 6{\cdot}8) \times 2240 \times 1{\cdot}15$

$= (15 \text{ tons} \times 2240)$ $= 33600$ lbs.

Total load $= 43960$ lbs.

Load on each beam $= \frac{43960}{6} = 7325$ lbs.

Assume 10 inches wide and 12 inches high section.

B. M due to concentrated load $= \frac{7325 \times 12}{4}$

$= 21975$ ft. lbs. or 263700 in. lbs.

Due to its own weight $= \frac{30 \times 12^2}{8}$

$= 540$ ft. lbs.

Total B M. $= (21975 + 540)$

$= 22515$ ft. lbs. or 270180 in. lbs.

$$f = \frac{270180}{(10 \times 12^2)}$$

$= 1120$ lbs. per sq. inch which is safe.

Dead load of Truss.

$8'' \times 10''$ piece 20 feet long	$= \frac{80}{144} \times 35 \times 20$	$= 389$ lbs.
$1\frac{1}{8}''$ rod 22 feet long	$= 3.38 \times 22$	$= 75$ lbs.
Side pieces 2 Nos. $3'' \times 10'' \times 8'$	$= \frac{60}{144} \times 8 \times 35$	$= 117$ lbs.
Shisham prop. ..	$= \frac{3 \times 1 \times 4.5}{12} \times 49$	$= 55$ lbs.
1″ dia. bolts 12 No. @ 4.5 lbs.	.. ..	$= 54$ lbs.
Bearing plates 2 Nos. ¼″ at ends	.. ..	$= 20$ lbs.
Other plates ..	.. ..	$= 10$ lbs.
	Total ..	$= 720$ lbs.
Weight per foot run $= \frac{720}{20}$		$= 36$ lbs.

APPENDIX III.

Estimated cost of various type of Boat Bridges.

Type I. **Single Boat 40 feet centre to centre, gunwale loading. (Old arrangement at Ghazi Ghat).**

Consider 1 span of 40 feet.

			Rs			Rs
1.	Bridge Boat 1 No.	@	1575/-	each	=	1575/-
2	Trussed Beams 4 Nos.	@	110/-	„	=	440/-
3.	Stiffening Beams 2 No.	@	33/-	„	=	66/-
4.	Cross Beams 2 Nos	@	14/-	„	=	28/-
5	Stiffening planks 2 Nos.	@	17/-	„	=	34/-
6	Roadway planks 36 Nos	@	11/-	„	=	396/-
7	Railing planks 4 Nos.	@	13/-	„	=	52/-
8.	Gunwale pieces 2 Nos	@	19/-	„	=	38/-
9	Wheel-guard 30 Rft.	@	1/8/-	Rft.	=	45/-
10.	Railing 30 Rft of bridge	@	2/6/-	„	=	71/-
11.	Cables wire-rope or chain 60 Rft	@	1/-	„	=	60/-
12.	Chain for stiffening Beams 20 Rft	@	-/12/-	„	=	15/-
13	Anchorage upstream and downstream			2 × 18	=	36/-
				Total	..	2856/-

(a) Total cost per foot run $= \frac{2856}{40} = 71/-$

(b) Cost of substructure per foot run $= \frac{1575 + 36}{40}$

$= \frac{1611}{40} = 40/-$

(c) Cost of superstructure per foot run $= \frac{2856 - 1611}{40}$

$= \frac{1245}{40} = 31/-$

Type II. **Single boat 30 feet centre to centre with central loading (New design adopted at Ghazi Ghat).**

Consider one span of 30 feet.

			Rs.
1.	Bridge Boat (improved design) 1 No. @ 1575/- each	=	1575/-
2.	Trussed Beams (King post) 7 Nos @ 116/- each	=	812/-
3.	Saddle Beams 6 Nos @ 27/- each	=	162/-
4.	Long Beam 1 No. @ 19/-	=	19/-
5	Roadway planks 26 Nos. @ 11/- each	=	286/-

6.	Railing planks 4 Nos. @ 13/- each	=	52/-
7.	Wheel-guard 30 Rft of bridge @ 1/8/- Rft.	=	45/-
8.	Railing-30 Rft. of bridge @ 2/6/- Rft.	=	71/-
9.	Cables, wire rope or chain 60 Rft. @ 1/- Rft.	=	60/-
10.	Anchorage for one boat 2×18/-	=	36/-
			3118/-

(a) Total cost per foot run $= \frac{3118}{30} = 104/-$

(b) Cost of substructure per foot run $= \frac{1575+36}{30}$

$= \frac{1611}{30} = 54/-$

(c) Cost of superstructure per foot run $= \frac{3118-1611}{30}$

$= \frac{1507}{30} = 50/-$

Type III. **Boat Bridge to carry I.R.C Loading.**
Single Boat 20 feet centre to centre with central loading.

Consider 1 span of 20 feet.

					Rs.
1.	Bridge Boat 1 No.	@ 1575/- each		=	1575/-
2.	Trussed Beams 7 Nos.	@ 100/- ,,		=	700/-
3.	Saddle Beam 6 Nos.	@ 30/- ,,		=	180/-
4.	Long Beams 1 No.	@ 24/- ,,		=	24/-
5.	Roadway planks 16 Nos.	@ 11/- ,,		=	176/-
6.	Railing planks 4 Nos.	@ 13/- ,,		=	52/-
7	Wheel Guard-20 Rft. of bridge @ 1/8/- Rft.			=	30/-
8.	Railing — 20 ,, ,, ,, 2/6/- ,,			=	48/-
9.	Cable, wire rope or chain 40 Rft. @ 1/- Rft.			=	40/-
10.	Anchors for one boat 2×18/-			=	36/-
					2860/-

(a) Total cost per foot run $= \frac{2860}{20} = 143/-$

(b) Cost of substructure per foot run $= \frac{1575+36}{20}$

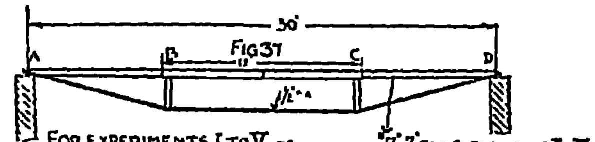
$= \frac{1611}{20} = 80/-$

(c) Cost of superstructure per foot run $= \frac{2860-1611}{20}$

$= \frac{1249}{20} = 63/-$

APPENDIX IV.

Tests on Trussed-Beams to destruction Queen-Post Trussed Beams.



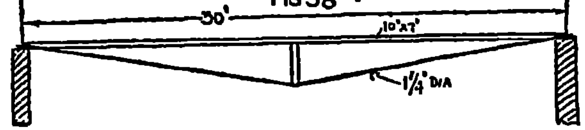
FOR EXPERIMENTS I TO V 2 TRUSSES AT 9' CENTERS
FOR EXPERIMENT VI SINGLE TRUSS

Experiment No.	Loading: Point of Loading	Loading: Manner of Loading.	Loading: Magnitude of Loading in tons	Observations	Remarks	Conclusions
1	2	3	4	5	6	7
I	B	Load on two Trusses 9 ft. apart	6 11½ 12¾	Deflection at B ½" in 1st beam and 1" in the 2nd " " 2½" " " 3" " Failed at B of top number.	Showed sign of fracture and cracking noise started	Experiments I to V showed that the strength of the beam is practically the same for all positions of the load. In every case the breaking load on each beam was about 5¾ tons, the top compression member failing in each case.
II	B		6 11 12	Deflection at B 1½" in both beams " " 2½" in One and 3" in the 2nd Failed at B of top number	" " "	
III	Centre of truss with 6 bolts at the joint		6 9 12	Deflection 1¾" in 1st beam and 1½" in 2nd " 2½" " " 2" " Beam failed by tearing of cover plates at the joint	Compression member showed signs of fracture and cracking noise.	
IV	Centre of truss with 2½ bolts at the joint.		6 10 11	Deflection 1½" in 1st beam and 1¾" in the 2nd " 3½" " " 3½" " Failed by tearing of cover plates at the joint	Cracking noise.	
V	Midway between A and B.		6 10 11½	Deflection 1½" in 1st beam and 1¾" in the 2nd " 2½" " " 2½" " The compression member failed at load point		
VI		Load on one Truss.	Nil 2¼ 4½ 6¾ 9 12	Camber 1" Camber nil Deflection ½" " 1½" " 2" Beam broke under point load	Beam was built with Camber of 1" Cracking noise started	

APPENDIX IV.

Tests on Trussed-Beams to destruction King-Post Trussed Beams.

Fig 38



Experiment No.	Loading: Point of Loading.	Loading: Manner of Loading	Loading: Magnitude of Loading in Tons	Observations.	Remarks.	Conclusions.
1	2	3	4	5	6	7
VII	Load mid-way between A and B	Load on single beam.	Nil 2¾ 4½ 6¼ 9 9½ 10½ 11½	Camber 2" " 1" " ½" " Nil Deflection ½" " 1" " 1½" Beam broke under load point	Beam was built with Camber of 2" Cracking noise started	The Experiments show that the king post trussed beam as designed can carry a breaking load of 12 tons and is twice as strong as the old type Queen-post trussed beam It is also observed that the King-Post trussed beam as designed is as strong as a Queen-post trussed beam having the same section for the compression member.
VIII	Beam made of Fir-wood inferior to Deodar load midway between A and B.		Nil 2¼" 4½" 6¾" 8½"	Camber 1¾" " ½" Nil Deflection ¼" Beam broke under load point	Beam built with camber of 1¾" Cracking noise started	
IX	B		Nil 2¼" 4½" 6¾" 9" 11" 12"	Camber 1¾" " 1¼" " ½" Deflection ¼" " 1¾" " 3½" Beam broke under load point	Beam built with camber of 1¾" Cracking noise started	

Thursday, October 7th, 1913.

Mr. Ali Ahmed (Chairman) called upon Mr. Khanna to introduce his paper, "Boat Bridge across the Indus at Gazighat".

The above paper was taken as read.

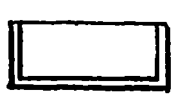
Discussion.

Mr. G. C. Khanna (Author) introducing his paper said :—

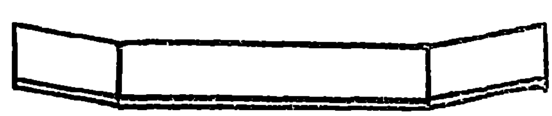
Since the outbreak of war road engineers who had to construct roads of Military importance crossing big streams and rivers, became interested in the subject of boat bridges. This is a subject which should be of equal interest to engineers after the war, on account of the suitability of a boat bridge for post-war development of roads. It requires minimum quantity of materials in its construction and costs very little as compared to a permanent bridge. It is easy to erect and dismantle, and if necessary, the entire equipment can be transported to any other crossing without much trouble.

Numerous enquiries regarding the boat bridge at Ghazi Ghat have been received from various parts of the country during the last two or three years. Certain improvements have also been made to increase the capacity of the bridge. Realising that the subject may be of interest, and as no literature is available on the subject, this lengthy paper has been presented to the Congress.

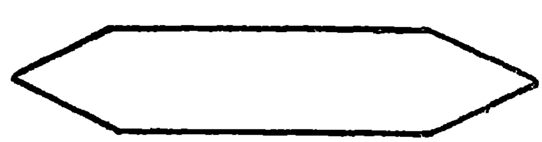
This paper gives a brief description of Gunwale Type-Boat Bridge which was used previously and of which a model has been shown to the members. The distance of boats from centre to centre is 40 feet and there are 4 trussed beams of queen post type carrying the roadway. The loading from queen post trusses is on the gunwale or edge of each boat. This bridge could carry a maximum of $2\frac{1}{2}$ tons of live load



SECTION



LONGITUDINAL SECTION



PLAN

The second model shows the improved type of the boat bridge. There are seven king-post type trussed beams carrying the roadway. These beams rest at the centre of each boat, therefore when live load

crosses the bridge, there is very little tilting of boats. This bridge can carry a live load of about 7 tons safely. Details of both types are given in Chapter III.

Chapter V, page 122, contains a description of the boat bridge to carry the Indian Roads Congress Standard Loading, which has been specified for arterial roads all over India. The bridge will be of the same pattern as centrally loaded type bridge shown in the second model. The spacing of boats will be reduced to 20 feet and the beams supporting the road will be slightly heavier. The roadway planks will be, however, of the same size.

It has been pointed out in the paper, that boats would sink too much when a ten ton roller crosses the bridge. Slightly bigger boats may be desirable.

In order to increase the buoyancy of the boats without increasing the size, it is suggested that the shape shown in Sketch may be adopted. *The existing boat is bow shaped, and is trapezoidal in cross-section.* The new boat will have a rectangular section, which is structurally more strong than a boat with a trapezoidal section. At its fore and aft ends, the edges of boat will be vertical and not inclined. Its buoyancy will be increased by about 6 tons. It will be equally stable in water, though the area on which water pressure is acting will be slightly increased.

A boat bridge designed to carry this loading will form no obstruction to traffic that is likely to come on roads in India. When hostilities cease, and post-war projects for development of roads start, this type of bridge will be suitable for most of the river and stream crossings on account of its economy. Money will not be easily available for permanent bridges which are very costly on account of their deep foundations and heavy training works. A boat bridge is put up when the discharge of the river is low and its width narrow as compared to its width during floods. A long bridge is not necessary, and therefore its cost is within reasonable limits. For instance a permanent bridge over the River Indus may cost more than one crore of rupees, while a boat bridge will not cost more than Rs. six lakhs.

It is fully realized that a boat bridge has to be dismantled during flood season, which may be for a period of about six months in a river like the Indus and for a period of about three months in a smaller river like the Ravi or the Beas. This handicap can be overcome by providing a ferry service.

I would like to mention here a few points which have come to my notice since the publication of the Paper regarding the maintenance of boat bridge.

(1) No traffic is allowed at night over the bridge.

(2) Motor vehicles are allowed at a speed of about 3 miles an hour over the bridge. In order to enforce this speed, a man walks before each vehicle. This speed is very irksome

to drivers of motor vehicles. and it is now proposed to have a cyclist going at a speed of about 5-7 miles an hour.

(3) Lorries loaded with passengers are not allowed to cross over the improved type of bridge It is feared by the Government that the hand rails are very flimsy, and a careless driver may topple the lorry into the river with disastrous consequences An accident like this has never occurred, but the Government does not want to take any risk.

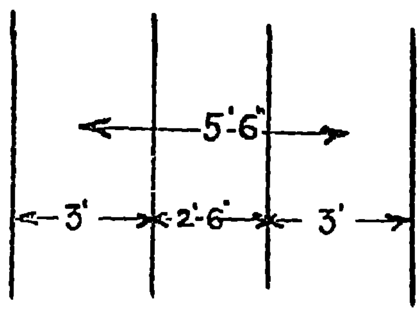
(4) Weighing appliances to check the weights of lorries and other vehicles going over the bridge, are difficult and expensive to get. A ferry boat used for crossing lorries and vehicles can be used for determining the weights of these. Advantge is taken of buoyancy of boat at various depths to determine the weight of vehicles. On all the four sides of the ferry boat, graduated scales are fixed which show the weight in the ferry boat at various depths. By loading the vehicles into the ferry boat and reading the scales, the weight of the loaded vehicles can be determined fairly accurately.

(5) A boat which can be separated into four parts was fabricated at site of works. The design of boat is shown in Plate XIII, page 105. We were afraid that the boat would develop too many leaks. It has been under observation for more than six months and I am glad to say that it is as water-tight as any other boat and its design can be safely adopted. A suggestion has been received that each of these parts should be so made that it can float independently. We are experimenting on the same

(6) I have pointed out a discrepancy on page 122 of the Paper regarding I. R C Standard Loading, and would like a member of Technical Sub-Committee on Bridges to explain it. What is the basis behind the I. R. C. Standard Loading ? Two different concentrated live loads, one for shear and the other for bending moment are rather confusing. What is our objection to reverting to the old 10 units British Standard Loading. The British Equivalent curve which has a scientific basis will come in very handy, and calculations will be easier.

(7) There is one more point which I would like to touch. This concerns the brick trackways that have been laid over the bunds. The trackways are 3 feet wide and 5½ feet centres. The trackways used to be laid previously at 4½ centres. This increase was made under the orders of the Consulting Engineer to Government of India, as new military vehicles had a width of about 5 feet to 5 feet 6 inches at the wheels. This track is much too wide for bullock carts or tongas, which use the roads primarily, and which have a track of 4 feet to

4 feet 6 inches. The wheels of carts are concentrated near the inner edges of the trackways as shown in sketch.



PLAN OF TRACKWAY

These wheels can never come near the outer edge of the trackways, as in that case one of the wheels could be outside the track. The wear on trackways is therefore near the inner edges, where ruts about 1 inch deep have been formed If trackways were laid 4 ft. 6 ins centres, the wear would be more uniform and all over the tracks It is suggested that trackways in future should be 4 ft. 6 ins centres. The military vehicles will be able to travel over these quite comfortably as the distance between outter edges of track ways will be 7 ft 6 ins.

K S. Raghavachary (Simla) :—

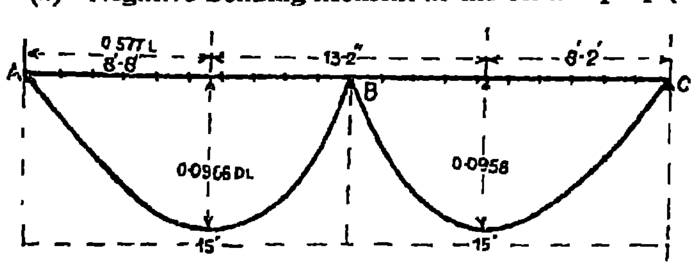
Mr Khanna's paper on "Boat Bridges" is the first of its kind in the papers so far contributed to the Indian Roads Congress, and the author deserves congratulation for his valuable contribution.

The principles of design adopted could be advantageously used for the construction of larger boats that could be used for the transport of food-stuffs etc

In the course of editing this paper, it occurred to me that the several formulae used require slight modification and these are detailed below Being mathematical, the author may consider these at his leisure and let us have his views before the proceedings are published and made available to members

I. Design of King-post-truss (pages 129 to 132).

(a) Negative Bending moment at the central prop (B).



Using the constants on pages 34-36 of "Concrete Plain and Rein-

forced" by Taylor Thompson and Smulski, 1938 edition, as adopted by the author, the negative B. M. under B due to rear-axle load will be

$$M = -0{\cdot}25\frac{a}{l}\left[1-\left(\frac{a}{l}\right)^2\right] Pr.\,l. \quad \ldots \quad \ldots \quad \ldots \quad \text{(i)}$$

where a = distance of load from left support
l = span, = 15 ft.
Pr = load = 3000 lbs.

For maximum value of M,

$\dfrac{dM}{d\left(\frac{a}{l}\right)}$ should be zero where $\frac{a}{l}$ is the variable.

Differentiating (i), we have,

$$1-3\left(\frac{a}{l}\right)^2 = 0: \text{ or } \frac{a}{l} = 0{\cdot}577 \quad \ldots \quad \ldots \quad \text{(ii)}$$

and M max = — 0·0966 $P.\,l.$ .. .. .. (iii)
= — 0·0966 × 3000 × 15 = —4347 ft. lbs. against
—4500 ft. lbs. (iv)

when this rear axle load P_r is at ·577 l or 8′-8″ from A or 6′-4″ from B for maximum B. M., the front axle load P_f will be 6ft.-10in. from the centre (see Fig.), as the wheel base is 13 ft.-2in. and $\frac{a}{l}$ for the front wheel will be $\frac{15-6{\cdot}83}{15}$ or 0·545 l.

(a in this case is to be taken from support C), and the front axle load will induce a bending moment.

$$M = -0{\cdot}25\frac{a}{l}\left[1-\left(\frac{a}{l}\right)^2\right] Pf.\,l.$$

$$= -0{\cdot}25\times0{\cdot}545\left[1-(0{\cdot}545)^2\right] 1500\times15 \text{ ft. lbs.}$$

$$= -2156 \text{ ft. lbs. against} -1800 \text{ ft. lbs.} \quad \ldots \quad \ldots \quad \text{(v)}$$

Total Bending moment = (iv) + (v) = 6503 ft. lbs. against 6300 ft. lbs. as worked out by the author (p130).

The total Negative B. M. due to dead and live loads will be
—(1800 + 6503) or
—8303 ft. lbs as against—8100 ft. lbs.

(*b*) **Reaction at the central support (p. 130.)**

It is not clear how the different reactions have been arrived at. Using the formulae

$$V_{2L} = (1-c\,9)\,P$$

$$= \left[1-\left\{\left(1-\frac{a}{l}\right)-0{\cdot}25\frac{a}{l}\left(1-\left(\frac{a}{l}\right)\right)\right\}\right] P$$

$$V_{2r} = 0{\cdot}25\frac{a}{l}\left[1-\left(\frac{a}{l}\right)^2\right] P$$

(formulae 77 and 78 on page 36 *ibid*).

$P_R = 3000$ lbs; $P_F = 1500$ lbs and $\frac{a}{l} = y$

$$V^{2L} \text{ due to rear wheel } = P_r \left\{ y + \frac{1}{4} y \left(1 - y^2 \right) \right\} \quad \ldots \quad \text{(vi)}$$

$$V \quad \text{,,} \quad = \left\{ y + 0{\cdot}25\ y \left(1 - y^2 \right) \right\} P_r \quad \text{(vii)}$$

$$V^{2L} \text{ due to front wheel } = P_F \left\{ 0{\cdot}25\ y' - \left(1 - y'^2 \right) \right\} \quad \text{(viii)}$$

$$\text{where } y' = \frac{2\,l - a - 13'\text{-}2''}{l} = (1{\cdot}12 - y)$$

$$V^{2R} \quad = \text{,,} \quad - P_F \left\{ y^1 + 0{\cdot}25\, y^1 \left(1 - y^{1^2} \right) \right\} \quad \ldots \quad \text{(ix)}$$

The total reaction = (vi) + (vii) + (viii) + (ix)

$$= 3000 \left\{ 1{\cdot}5\ y - 0{\cdot}5\ y^3 \right\} + 1500 \left\{ 1{\cdot}5(1{\cdot}12 - y) - 0{\cdot}5\ (1{\cdot}12 - y)^3 \right\}$$

$$= 1500 \left\{ 3{\cdot}348\, y - 0{\cdot}5\, y^3 - 1{\cdot}68\, y^2 + 0{\cdot}9775 \right\} = f(y) \quad \text{(x)}$$

This will be maximum when $\frac{d\,(fy)}{d\,y} = 0$

(i.e.) when $3{\cdot}348 - 1{\cdot}5\, y^2 - 3{\cdot}36\, y = 0$

or $y = 0{\cdot}755$

substituting $0{\cdot}755$ for y in (x) the total reaction 3500 lbs. as against 3420 lbs.

(c) Positive B. M. at the centre of the span.

On page 130, the author states that the maximum positive moment will occur at the centre of the span when hind wheel is over it. This is not quite accurate The positive B. M. is given by the formula.

$$M = C_9\ P.\,a, \text{ where } C_9 = \left[\left(1 - \frac{a}{l} \right) - 0.25 \frac{a}{l} \left\{ 1 - \left(\frac{a}{l} \right)^2 \right\} \right]$$

$$= 1 - 1.25 \frac{a}{l} + 0{\cdot}25 \frac{a^3}{l^3}$$

$$M = P \left(a - \frac{1{\cdot}25 a^2}{l} + 0{\cdot}25 \frac{a^4}{l^3} \right) \quad \ldots \quad \ldots \quad \text{(xi)}$$

differentiating with respect to the variable a/l for maximum bending moment we have $\frac{1 - 2.5\,a}{l} + \frac{a^3}{l^3} = 0$ (xii)

$$\text{or } \frac{a}{l} = 0{\cdot}4325$$

and M max = 0.207421 (as against 0 210 Pl as worked out by the author)
= $0{\cdot}20742 \times 3000 \times 15$ or 9334 ft. lbs as against 9450 ft lbs.

The maximum positive and negative bending moments, and reaction at the central support as worked out above and by the author are tabulated below.

	As worked out above.	As worked out by the author.
Max. Positive BM at centre of span ft. lbs.	9334+1010=10344	10,500
Max. Negative BM at B. ft. lbs.	95031+800= 8303	8,100
Reaction at the prop lbs.	3500+1200= 4700	4,620

The working stresses in the various members as worked out above and by the author, page 131, is tabulated for easy comparison.

	As worked out above. lbs. per sq. in.	As worked out by the author. lbs. per sq. in.
Direct compression in the strut.	$\frac{4700}{12 \times 4\cdot5} = 87$	86 ,, ,, ,,
bearing stress on top of member.	$\frac{4700}{7 \times 4\ 5} = 149$ or 150	150 ,, ,, ,,
Bearing on $1\frac{1}{8}$in. dia. rod	$\frac{4700}{1\cdot125 \times 4\cdot5} = 927$	913 ,, ,, ,,
Stress in the tie rod	15268	15,000 ,, ,, ,,
Stress in members AB and BC	1232 in compression. 896 in tension.	1245 compression 915 tension
Tension at joint B.	902	884

II. **Design of saddle beam.**

On page 133 the whole of the live load of 8 tons has been assumed to come on the saddle beam. In actual practice, maximum stress would be produced when the rear wheel is over the saddle beam and the load carried would be

$$5\cdot33 \times 2240 + 2\cdot67 \times 2240\left(\frac{30-13\ 16}{30}\right)$$

or 15290 lbs. as against 17,920 lbs worked out by the author.

$\therefore$ Load on each beam $= \frac{13660 + 15290}{6} = \frac{28950}{6} = 4825$ lbs. as against 5260 lbs. as worked out by the author.

Design of Bridge for I. R. C. loading (page 142).

The load on a traffic lane of 10 ft. is assumed distributed over the full width of the bridge which is 12 ft. and design of trusses is based on this assumption. Though the code of practice does not deal specifically with such cases, it seems to me to be rational to assume that the live load is carried by trusses in 10 ft. width of the bridge only. This is in conformity with B.S.S. 153 on bridge loadings and this is being adopted by the Indian Railway Board.

The stresses in various members are worked out below on this basis.

Distributed live load per foot run including 15 per cent impact. $\left.\right\}$ $\frac{0.34 \times 2240 \times 1.15 \times \text{spacing}}{10}$

= 175 lbs against 125 lbs

K. E Load. $\frac{6 \times 1.15 \times 2240}{10} \times 2$ = 3091 lbs against 2200 lbs.

K. E. Load for shear. $\frac{9 \times 1.15 \times 2240 \times 2}{10}$ = 4637 lbs. against 3300 lbs.

Negative B. M. due to dead load. $1/8 \times 175 \times 10^2 \times 12 = 26250$ in lbs as against 18720 in. lbs

Positive B. M. at 0.375 l = $\frac{9}{128} \times 175 \times 10^2 \times 12 = 14766$ in lbs. as against 10320 in. lbs

B. M. due to Knife edge load

Positive B.M $3091 \times 0.207 \times 10 \times 12 = 76{,}780$in. lbs as against 55,200in. lbs.

Negative B. M. = $3091 \times 0.0966 \times 10 \times 12 = 35831$ in. lbs. as against 26400 in lbs

Therefore Max. Negative B. M. = $26250 + 35831 + 10800 = 72881$ in lbs. as against 55920 in. lbs.

Max. Positive Moment = 6072 (D.L.) + $14766 + 76780 = 97618$ in. lbs. as against 72000 in. lbs.

Max. shear at B.(p 143) = $\frac{175 \times 20 \times 5}{8}$ = 2188 lbs.

Due to K. E. load	4637 „
Due to dead load	900 „
	7725 lbs. against 5760 lbs

Determination of size of members :—

Direct compression = $\frac{7725}{12 \times 4.5}$ = 143 lbs. per sq. in as against 110 lbs. per sq. in.

Bearing stress $\frac{7725}{8 \times 4.5}$ = 215 lbs. per sq. in. as against 160 lbs per sq. in

Bearing (1⅛ in. dia. rods) = $\frac{7725}{1.125 \times 4.5}$ = 1525 lbs. per sq. in as against 1118 lbs per sq. in.

Stress in AD and CD $\frac{7725 \times 10.44}{3 \times 2}$ = 13422 lbs as against 10,000 lbs

Stress in rod = $\frac{13442}{0.78}$ = 17,233 per sq. in as against 13,000 lbs. per sq. in

Direct stress in AB,BC = $\frac{7725 \times 10}{3}$ = 25750 as against 19200 lbs. -do-

(p. 144)

Max Positive B. M. = 97,618 in lbs.

f_c or f_t = $\frac{25750}{8 \times 10} \pm \frac{97618 \times 6}{8 \times 10^2}$ = 1045 or 410 lbs. per sq in. as against 780 or 300 lbs. per sq. in

Design of Joint B.

Max. Positive Moment = 72,881 lbs. as against 55920 in. lbs

Tension in joint, $= \frac{25750}{14 \times 10} \pm \frac{72881}{6 \times 10^2} = 545$ lbs. per sq. in. as against 442 lbs. per sq. in.

Design of long beam.

Distributed live load $= \frac{6.8 \times 12}{10} \times \frac{2240 \times 1.15}{7} = 3000$ lbs. as against 2500 lbs.

K. E. load. $\frac{12}{10} \times \frac{6 \times 2240 \times 1.15}{7} = 2650$ lbs. as against 2200 lbs.

Dead load. $\frac{2 \times 72 \times 20}{2}$ = 1440 „ „ 1440 „

Total dead and live load. = 7090 lbs. „ 6140 lbs.

B. M. at centre $\frac{7090 \times 2}{5} = 2836$ ft. lbs. as against 2456 ft. lbs.

B M. at end due to cantilever $7090 \times 1.3 = 9217$ ft. lbs as against 8000 ft. lbs. Stress $= \frac{9217 \times 12 \times 6}{8 \times 10^2} = 830$ lbs. per sq. in. as against 720 lbs. per sq. inch.

Max.shear. $= \frac{8414}{80} = 105$ lbs. per sq. inch as against 90 lbs per sq. inch.

Page 145.

Saddle beam.

Dead load	$= 72 \times 7 \times 20$	= 10080 lbs.
Wt. of beam	= (8in. × 10in. × 14ft.)	= 280 lbs.
Live load	$(6+6.8)\ 1.2 \times 2240 \times 1.15$	39567 lbs.
		49927 lbs. as against 43960 lbs.

Load on each beam $\frac{49927}{6}$ = 8321 lbs. as against 7325 lbs.

B M. due to self wt $= \frac{30 \times 12^2}{8} = 540$ ft lbs. as against 540 ft. lbs.

B. M. due to live load $= \frac{8321 \times 12}{4} = 24963$ ft. lbs as against 21975 ft. lbs.

Therefore total B. M. = 306036 in. lbs as against 270180 in. lbs.

Therefore $f = \frac{306036}{240} = 1275$ lbs. per sq. in. as against 1120 lbs. per sq. in.

On page 122 of the paper, the author states that he does not know how the Indian Roads Congress Bridge Loadings have been derived. Attention is invited to pages 250 to 269 (and the plates) of the Proceedings of the Congress, Vol. III, wherein the evolution of these loadings has been fully dealt with.

It may be mentioned that the variation in the stresses, as worked

out by the author and as revised in the above notes, does not materially affect the sections of the various members. When dealing with the subject theoretically, it appears necessary that the calculations should be based on the correct formulae and made to reasonable accuracy.

Mr R. Trevor Jones (Punjab) (Correspondence) :—

As I shall be unable to attend the 8th Indian Roads Congress, I should like to write some notes on this paper.

This paper is to my mind an extremely valuable contribution not only from the Punjab aspect, but as an example of what can be done with existing equipment to adapt it to modern conditions of loading. The boat bridge equipment which we possess in the Punjab was originally designed by the famous General Sir Alexander Taylor very many years ago and was no doubt all that was required to carry the loads then in existence. Mr. Khanna has redesigned the bridge by the use of saddle loading, an improved type of trussed beam, and has increased the size of the ribs and the boats, to carry a gross load of 8 tons, but this is a war measure and has been satisfactorily tried out for the past year or so. He has gone a step further and now made it possible to adapt this existing boat bridge equipment to carry I R C loading and has also evolved an idea of making the boats easily transportable That it is possible to develop and redesign this archaic boat equipment to meet modern needs is to my mind one of the most valuable features in this paper In India, as elsewhere, we are trying to plan for post-war conditions Our greatest obstacles are not so much natural and climatic conditions, difficulties of supply, political questions etc. but the unbending and insurpassable obstacles placed in our way by the financial mind. Road construction is not popular from the financial aspect It shows no return for the money expended. It is considered an unnecessary and almost luxurious expenditure of public money If this view is taken with regard to roads it infinitely more so obtains for bridges, as the latter are far more expensive per foot run In the Punjab it is not an uncommon thing to find a perfectly good arterial or trunk road severed in the middle because no bridge has ever been provided by the benign Government In fact the writer can testify that there were no permanent road bridges, when he first came into service 30 years ago over any of the five main Punjab rivers unless they happened to be combined with the railway crossing As in many other provinces, the Punjab is preparing a road scheme for post-war development Many of these roads require important bridges In fact in our present programme we want something like 40 major bridges to be constructed It is unlikely that, even if it were possible to pierce financial resistance it would be practical to obtain supplies of steel and cement in view of the enormous demands for building material immediately at the end of the war or even sometime after Can we not, therefore, throw temporary bridges across these main rivers as is done in time of war by the Royal Engineers and make use of and adapt such temporary equipment and material as we possess such permanent structures can be constructed? It is here that I feel that the technical research rendered by the author is of the greatest value. There are disadvantages, as such temporary floating bridges are vulnerable in flood time, but on some of the major Punjab rivers such bridges are kept open throughout the year. The writer of this note has recently seen a great deal of Ameri-

can and British Army pontoons and it is possible that such equipment might be available for civil needs after the war. It would be excellent if this were possible as the equipment is of a most modern nature and will carry practically any loads likely to come on our roads; but it is not very probable that such facilities would be available or be financially welcomed

Furthermore immediate benefit from any Post-war Development Schemes which needs must be comprehensive and thus involve the expenditure of large sums of money cannot be expected, unless and until the main rivers and streams across them are bridged. As the construction of these bridges must necessarily not only involve expenditure of huge sums but must also take considerable time, it may not always be possible to provide permanent crossings at every place. Moreover the traffic needs at some of the crossings may not be such as to justify an expensive permanent crossing to be built for many years to come. In such cases it would be just as well to conserve that money and use it where it would justify itself and yield immediate benefits.

The work of the author in improving the design of the Boat Bridge to make it capable of carrying modern intensities of traffic and loads is therefore of considerable value in any work of post-war development of roads in this country and would be found most interesting and useful.

G.C. Khanna (Author) :—I am very grateful to Mr. Raghavachary for working out the calculations for design of King Post Truss from first principles I agree with his detailed analysis of stresses These calculations will be a useful supplement to the paper.

It will however be seen that values of stresses worked out by me are not materially different from those worked out by him Mr. Raghavachary has himself made a comparison and shown that differences are trifling. Engineers who are busy in office work, can safely use the formula given by me.

I regret there has been slight mistake made by me in the Design of Saddle beams. Calculations made by Mr. Raghavachary are correct.

I.R.C. Loading.

As the Boat Bridge is to carry a single lane of traffic, the whole load, in my opinion, should be distributed over all the trussed beams. The entire live load will be distributed by planks on all the trussed beams, therefore my calculations are correct. If the roadway were 8 feet only, will the loads on trussed beams be reduced proportionately ?

Even according to Mr. Raghavachary's method, the sizes of members will not be materially different from those worked out by me

I acknowledge with thanks the encouraging remarks made by Mr. R. Trevor Jones, C.I.E., Chief Engineer, P.W.D., regarding my paper. Boat Bridge is bound to play an important part in the Post-War development of roads. Its initial cost is very low and therefore bridging of rivers by boats will be a first step in the development of communication. When traffic increases sufficiently, boat bridge can be replaced by permanent bridge.

PAPER No. G—1943.

*SOME NOTES ON THE MAINTENANCE OF WATER BOUND MACADAM ROADS

BY

RAO BAHADUR A. LAKSHMINARAYANA RAO, B.A., B.E.,
Superintending Engineer, Special Roads Circle, Chepauk, Madras.

1. Introductory.

Funds available for constructing and maintaining roads are at present very inadequate, and with competing demands of various other but more clamorous nation-building activities, more funds are not likely to be provided by the Authorities controlling finance. All the available intelligence and industry should therefore be directed to make the present allotments go a longer way by avoiding uneconomical and wasteful methods and by drawing up correct programmes. An attempt will be made in this paper to give a few ideas as to how this can be done in the case of rural roads, though some aspects may apply to urban areas also.

2. Providing proper types and widths to roads.

Any section of a road should be so maintained as to efficiently carry the traffic on it. Water Bound Macadam can bear traffic only up to a limited extent With increased widths, (two lanes or three lanes), it can carry heavier traffic. But generally, for very heavy traffic, a higher type of road is necessary and economical. By working out the amounts spent on uneconomical methods for a period of say 10 years, the Road Engineer should show how funds spent on maintenance of bad types can be saved. Grants should be distributed not on a territorial but on a traffic basis. Short lengths of correct types should be also constructed for comparative study, thus educating the administrations controlling funds. In short, the Road Engineer has to strive and create what may be called road appetite in the public.

3. Economic thickness of renewals.

It is well known that the cost of renewals varies directly with the quality and quantity (thickness of renewal) of metal used, as the cost of picking and consolidation is nearly a constant figure. Hence the thickness of renewals should be the economic minimum, depending on the thickness and nature of the existing crust. A regular renewal of 2 inches or 3 inches once in 2 or 3 years is not necessarily the best way and often gradually raises the level of roads, to an un-desirable extent, especially over long bridges increasing the dead weight of the bridge. Where there is a metal crust of 6 inches or more, it is unnecessary to have renewals thicker than 1½ inches with hard metal of 1¼ inches I.R.C. Gauge. In such cases, it is enough to thoroughly pick up the existing crust to a depth of 2 inches; remove the excavated stuff on to the berms ; pick and section the bottom; screen and collect good metal from the picked stuff, and spread it back

*Due to shortage of paper, the original paper has been somewhat abridged.

on the road, and then spread new metal to a depth of 1½ inches. The total depth of the old and new metal will be nearly 2½ inches loose and 2 inches when well consolidated Thus less metal is used, making the renewal less costly. Also, the road level is not raised This will not apply to softer metal, as there will not be much useful stuff from the picked surface The thickness of the renewal may then be 3 inches.

4. Quality of metal to be used.

In localities where quarries yielding good hard metal like granite, gneiss, trap, etc, are easily available, there is no question of the selection of proper quarries. There is also no difficulty in localities where soft varieties like kunker and laterite alone are available and the traffic on the roads is light. The trouble arises where harder varieties of metal are necessary for the traffic, but are costly and have to be imported from long distances by carts, boats or rail and softer varieties are cheap. In such cases, an examination of relative costs on the following lines is necessary:

If Ch is the cost of 100 cu ft of hard metal
Cs „ „ soft metal
Cg „ „ gravel
the cost in rupees for renewal of one furlong of road 12 ft wide will be
(1) for a 2 in. renewal with hard stone 13 2 Ch + 60 + 4 4 Cg
(2) for a 3 in. renewal with soft metal 19 8 Cs + 60 + 4 4 Cg

This assumes that the cost of consolidation excluding cost of materials is Rs. 60/- per furlong for a 3 in renewal with soft metal, or a 2 in hard metal recoat and that as much gravel is used for both these types of renewals. Assuming the life of a hard type of metal is at least twice as much as that of a soft type, and with an average cost of Rs 4/- per 100 cu ft of gravel, the substitution of hard metal for soft metal is not more costly if—

$$13\ 2Ch + 60 + 4\ 4Cg \text{ is not more than } 2\ (19\ 8Cs + 60 + 4\ 4Cg)$$

$$\text{or} \qquad Ch \text{ is not more than } 3Cs + 6$$

It, therefore, follows that as long as hard metal does not cost more than three times that of soft metal, it is economical to go in for hard metal Also, after some time, renewals with hard metals can be reduced to 1½ inches as stated in para.-3 Adoption of a harder type of metal will be all the more economical in the long run, even when the cost of hard metal is 3 times that of the soft one It is needless to observe that where this cost is less than 3 times the cost of the soft variety, hard metal should be preferred.

5. Cambre

The cambre or cross slope should be such as to enable the rain water to flow to the sides and thus to keep the subsoil dry and hard Water stagnating on the road, soaks through the metal crust, moistens and softens the subgrade forming pot holes Under heavy traffic, the crust also wears out more quickly if the surface is wet.

The Road Research Laboratory of the Department of Scientific and Industrial Research, in co-operation with the Ministry of Transport, recommend a cross fall of 1 in 30 for Water Bound Macadam (plain or surface dressed). A cross fall of 1 in 48 to 1 in 36 is the least that can be adopted for the conditions prevailing in this country, the former for areas with less intensity of rainfall and the latter in areas where cyclonic out-bursts are common.

6 Berms

Well maintained berms 7 to 8 feet wide are good adjuncts to a heavily trafficked road particularly when the metalled width is only 12 ft. They will enable vehicles to cross and overtake each other easily, entice traffic during the dry season and provide a diversion route during the period of consolidation But berms wider than 7 or 8 feet are very costly to maintain and also not necessary, as their maintenance will be at the expense of the main road. These berms should also have good cross slope so that rain water may not stagnate, soak into the berms, rendering them unfit for use by traffic. The slope should be 1 in 36 in the case of hard and compact soils, and 1 in 24 in the case of soft soils Gullies in the berms should be promptly closed. The sides of the berms should have a slope of 1½ to 1 in gravelly soils and 2 to 1 in soft soils Growth of turf should be encouraged on the slopes and the top of berms by planting turf pods in rainy season. The grass should not also be allowed to be scraped by villagers. The vicious practice of stacking metal on the berms should be put down

7. Consolidation of renewals

The cost of consolidation will generally be not more than one-third of the cost of materials, but if consolidation be not properly done, the value of both collection and consolidation is lost. Roughly ⅓th crore of rupees are spent on road maintenance in Madras and it may not be far wrong, if it be estimated, that 6 crores of rupees are spent in the whole of India on road maintenance Yet it will not be an exaggeration, if it be stated, that this work of consolidation does not receive, at the hands of supervisors one-tenth the attention it deserves When a bridge or building is under construction, the Divisional Officer, the Sub-Divisional Officer, and the Supervisor, all pay close and careful attention to every detail of work and see that the specifications are strictly enforced. The same cannot, however, be stated of road works, such as picking and rolling, though the economic use of large amounts on roads depends on these two operations. Specifications drawn up for picking up the road surface, spreading metal, rolling etc should be observed carefully. For hard types of metal, rolling should be adequate. The roller must be run on each foot width of road at least 30 times This requires that for a metalled width of 12 ft., with a roller 5 ft 4 in. wide, 90 trips should be made in all. The average speed of a roller on the road is about a mile an hour and it would ordinarily take 12 hours of rolling to thoroughly consolidate a furlong of hard metalled road and officers should ensure that this rolling is actually done for the required number of hours. In this connection, it is suggested that speedometers showing the total distance travelled be fixed to each roller to check the rolling done.

The weight of a roller used for consolidation should depend on the quality of metal used. Softer varieties like kunker and laterite require lighter rollers, or the metal will be crushed to powder and not get consolidated Harder varieties of metal like granite require heavier rollers.

Water should be correctly used during consolidation. Too much watering is as bad as too little watering. In the earlier stages when rolling is done on metal, water should be just sufficient to keep the subgrade moist so that the hoggin below may rise up helping the interlocking of metal Gravel should not be spread until the interlocking of metal is complete It is laid down in almost all specifications that gravel should not be spread till the rolling over metal is so thoroughly done that there is no creep in the metal when the roller passes over it, or a laden cart can pass over the surface without making a groove This is not always observed, and contractors are prone to throw gravel on the incompletely-rolled metal surface. Spreading of gravel before the consolidation of metal is thorough, will result in a mass of mud-stone-concrete presenting a false smooth surface temporarily Its true weakness will be exhibited after a short time Gravel is soon powdered by traffic and blown off by the winds and fast motor traffic, and a knobby surface or a surface of floating stones soon shows itself, neither of which is welcomed by traffic The surface soon becomes rough and all the money spent on the renewal will not have been usefully spent

8 Drainage.

The proper maintenance of a road in the rainy season depends very much on the attention paid to the disposal of the drainage from the sides of a road Roads do not always run on ridges and have to be protected from the damages that will be caused to them by the rain water flowing either over the road or along it Where there are no culverts or bridges, rain water has to be led away intelligently to low natural drainages In sloping or through hilly country, with series of ups and downs, rain water should not be allowed to flow along the road A clogged drain easily causes overflow and damage to the surface Any amount of attention paid to the metal surface will not be of much avail if adequate attention is not paid to drainage In distributing the allotments given to a road, sufficient provision should be made for proper maintenance of the drains, and the Engineer in charge should see that these drainage works are executed in time

9 Gang coolies for patch repairs and miscellaneous works.

The old saying that "A stitch in time saves nine" applies with great appropriateness to roads. The embryo pot hole, if promptly patched up, saves the road from developing large pot holes thus postponing the renewals for some more time Timely blinding with proper materials after watering the surface will prevent the breaking up of the metal besides maintaining a smooth riding surface free from knobs, and timely attention to drains and gullies will prevent damage to road, ultimately saving large amounts These and other petty works to be attended to on a road require the employment of a set of gang coolies It is false economy to dispense with the services of these gang coolies to save money for collecting greater quantities of metal or for renewing a greater number of furlongs.

10. **Allotment required for the annual maintenance of Water Bound Macadam Surface.**

Roads should be taken up for maintenance only after they are properly constructed An ill-built road thrown open hastily for traffic is always bound to cost large amounts on maintenance.

The amount required for maintaining a well-constructed road depends on :—

(1) traffic intensity,
(2) life (in years) of the available metal under the traffic conditions,
(3) cost of metal,
(4) rainfall and topographical conditions of the country.

In addition, a certain allotment is also necessary for minor maintenance such as patch repairs, closing up of gullies, clearing drainages etc.

Taking the life of a 1½ in. coat of renewal with hard metal as

4 years for traffic upto 200 tons per day ;
3 years for traffic from 201 tons to 500 tons per day ;
2 years for traffic from 501 tons to 800 tons per day ,

the following empirical formula has been evolved by the author based on his experience in the Madras Presidency. This has been found to give fairly accurate results with a margin of 10 per cent.

$$A = \left(C\frac{T}{15} + 12 \right) + \frac{T}{5} + 50$$

where A is the allotment in rupees required per mile per annum,
C is the cost in rupees of 100 cu ft. of metal,
T is the daily intensity of traffic in tons.

11. The intention of the author in presenting these notes before an eminent body of Engineers is only to focuss attention to the petty details which are often overlooked but which go a long way in securing lasting and economical road maintenance thereby increasing the "road-rupee ratio".

Monday, October 4th, 1943.

Mr. Vesugar (Chairman) :—I call upon Mr. Lakshminarayana Rao to introduce his paper "Some notes on the maintenance of water-bound macadam roads".

The above paper was taken as read.

Discussion.

Mr. K. S. Raghavachary introducing the paper read the following note on behalf of the author :—

I regret very much that exigencies of service prevent me from introducing this paper before you in person and I apologise to the Indian Roads Congress for the same. I have requested Mr. Raghavachary to kindly introduce the paper on my behalf. My sole object in submitting the paper is to focuss the attention of the Road Engineers to the possibility of greater attention being paid by the officers to consolidation and to plead that more attention will go a fairly long way in increasing the Road-Rupee-Ratio. An attempt has been made to show how, by adopting economic, renewals, greater milage of roads can be maintained in a better condition.

The following errors in printing may please be corrected :—

(1) page 151 (3) in the 6th line after the words "the best way" the words "of maintaining a road" may be inserted.

(2) In Page 155, the bracket has to come after C and not before C. The formula† should read as

$$A = C\left(\frac{T}{15} + 12\right) + \frac{T}{5} + 50$$

Mr. N. T. Gnanaprakasam (Madras) :—

Cambre. The cross fall of 1 in 30, suggested for water-bound macadam, appears to be far too much One of the factors to be considered in deciding the cambre is the nature of material used in making up the road. On the whole for metalled roads, a cross fall of 1 in 48 to 1 in 72 appears to be sufficient. A flatter cross slope gives scope for better distribution of traffic and reduces the tendency for rut formation which is more evident with steeper cross slopes.

The learned Author suggested the encouragement of turf-growing on berms. It is common experience that as long as there is any turf or grass growing on the berm, traffic avoids the margins. It is probably better to have the margins clear of everything including grass.

No mention has been made of gravelling of berms which is a very important item in the upkeep of roads. It not only helps to make the

† The formula as printed on page 155 is as originally given by the author in his paper—Ed.

berms occasionally trafficable but also helps to prolong the life of the road A stretch of road which has its margins gravelled simultaneously with its renewal, lasts much longer and provides a much better surface than a stretch where the margins are not gravelled especially in black cotton soils The slight expenditure involved in gravelling the berms is more than justified by the extra life and better surface we secure

Consolidation —It is stated that a roller would require to make 90 trips in order to cover each foot width 30 times But 70 trips of the roller would be enough to cover the whole width thirty times The time required which is stated to be 12 hours is also too much and about 9 hours should be enough to do the 70 trips

The idea of a speedometer is an excellent one and should commend itself to Road Engineers who have at present no effective means of checking the amount of rolling done

Mr. T. Lokanatha Mudaliar (Madras) :—Water-bound Macadam is the translation of rock from quarry to road, through the practicable method of taking the broken rock and resetting it on the road; while resetting, our attempt is to place the broken stone on the road in as compact a manner as possible, reducing the voids to a minimum, and filling the inevitable voids with something which will stay put, and to make the flattest and smoothest faces of the broken stone form the wearing top surface, by a process spoken of as consolidation The roller is today the most popular tool for this consolidation. In effect our attempt is to make a stone-cum-gravel concrete, with a smooth stone-finish. The heavy roller adjusts the stones to a co-operative compactness (you may call it interlocking, if you like), and tilts the stones by their sharp corners until the stones are having their flat faces upturned. The function of the roller is not to break, crush, or otherwise injure the stones The function of the binder is to fill up the voids, and in a way, also to bind the stones The binder, however, should not keep stone apart from its neighbour If this is properly done, there should not be

(1) Wheel ruts which appear in the very first week after consolidation,
(2) those corrugations which remind us of a sea-voyage,
(3) those pot-holes indicative of soft subgrade or scampy rolling,
(4) that roughness and break-up which is the tyre manufacturer's friend, and country's enemy.

About 75 per cent. of our water-bound macadam roads may be seen to be allowed to fail in one or more of the four ways mentioned above. This, you will agree, is not because of the impossibility of achieving the desired result, but because of the contempt and neglect born of familiarity Many think that the thing is so simple that a road cooly can make; perhaps he will, if left entirely to his good sense and knowledge of the local materials and weather The fact is that the very road engineer who is responsible for making and maintaining the water-bound macadam does not realise that it requires the knowledge of a scientist, and the skill of a jeweller; that it is not merely *a formal matter of reducing the trapezoidal section* of the metal heap to a rough rectangular, rhomboidal, double convex, plano-convex, or

concavo-convex section on the road I am afraid we are too complacent, or put it down to a sort of Engineering Kismet, when we see the water-bound macadam fail under traffic of less than 300 tons per day. In our Road Congress meetings, we devote little time to this vast, and inescapable subject, or only as much time, perhaps, as talk about God usually occupies among the discourses of Theologians who, for mundane reasons, are more absorbed in the means of holding their congregations interested in the theologian himself rather than in God. We have, therefore, good reason to have the paper under discussion, all the more so, as it comes from one whose harangues on the black-top have rung in the Roads Congress meetings erstwhile ; may be this is due to his having to turn, however reluctantly, to this water-bound macadam in the absence of those barrels which used to black-dot some of our roads; or, may be due to the fact that in his province, a new Chief Engineer, a Mac has come to re-apostolate Mac-Adam, —who is mighty keen on getting the best out of the inevitable water-bound macadam.

There seems to be a fallacy among the road engineers that the higher they are placed, the higher should be the figures in which to think of road making. Trifles pass beneath their notice. We have seen rich people discarding cheap pot-herbs and leafy vegetables as too cheap for their fat purses; and then visiting costly clinics, and luxurious invalid homes. Likewise the high Highway Engineer, endowed with a costly well-sprung car, is keen only on speed, bituminous surfaces and so forth. What grinding the bullock cart is obliged to make on a rough road, what silent suffering the poor draught animal undergoes when the cartman leads it to its early grave, is not noticed by him. His questions are—what is the rotation of renewal ? When was this particular mile last renewed ? You say your estimates for renewals were turned down for want of funds; why do these wretched villagers want so many new roads to starve the existing ones, and when we can't have a single road in the district decent enough even to get a petty forty mile-an-hour drive on this powerful car which beams with a dial showing 100, all for nothing. He thus passes from one excited thought to another. Does he stop a while to think what it is that keeps the surface in eternal ruin ? Has he walked by the side of a heavily loaded cart watching its rumble-tumble progress? Has he noticed how, when there is a hump, the hit and fall of the wheel makes for two new pot holes, how when the wheel gets on to a knobby stone that side of the cart is lifted by an inch or so, how the bullock will with a sneer avoid the rough unblinded road as poison (some may ironically say that this works for welcome segregation)? Has he noticed that on a stretch with a heavy cambre, the bullocks keep up the regulation of yoke pressure by keeping to the crown, causing deep wheel-ruts, if, and when he does notice ?

Mr. Ali Ahmed (Assam) :—On page 154 the author has stated in paragraph 9 of the paper "Timely blinding with proper materials after watering the surface will prevent the breaking up of the metal besides maintaining a smooth riding surface free from knobs". I wish to lay emphasis on this as this method was found very useful in Assam to prevent ravelling of metalled surface under motor traffic. In case of the Dibrugarh-Khowang road where the road metal used is of a very

hard type broken from *Lobo* boulders brought out of the bed of the Brahmaputra, it was found that within few months after periodical consolidation, metal would come out and the road would become execrable. This was dealt with by watering and spreading loamy earth along the tracks, and this being done regularly by road gangs, it was found that no unravelling occurred due to the suction effect of motor car tyres The road was kept in good condition by this process, which is now generally adopted over all water-bound macadam roads in the province.

The expedient of using less metal in the renewal coats but increasing the frequency of rolling was also found successful in giving a better riding surface Our experience in Assam differs, therefore, from that of Mr Ahmed Mirza in Hyderabad who advocates a greater thickness of metal and longer intervals of consolidation I do not quite understand what is his definition of dead metal as opposed to live metal, but picking up the old surface and re-using old metal, with new metal added to it, has not proved defective in practice, and it would involve a good deal of waste if a considerable proportion of old metal is to be rejected after the surface is picked up for giving a renewal coat

One of the speakers has advocated a flat surface for hill roads. Assam has many hill roads such as the Dimapur-Manipur Road, the Gauhati-Shillong Road, the Shillong-Sylhet Road, and on all these roads the surface is cambered in the ordinary way. A flat surface is undesirable as the tendency of rain water would be to run along the road which can only do harm and cause inconvenience to traffic

CORRESPONDENCE.

Mr. M A. Mirza, Hyderabad (Deccan):—Rao Bahadur A Lakshminarayana Rao must be congratulated on bringing up for discussion a subject matter of such vital importance to Road Engineers in India and, yet, which has received hitherto only the scantiest of attention.

Barring a few honourable exceptions, the road systems of India consist mostly of water-bound macadam surfacing These roads are maintained on empirically fixed maintenance grants although they vary for each class of road. Those who have had to do with the maintenance of roads will corroborate me when I say that this system may be approximately correct but there are occasions when the maintenance grant either proves in excess of the actual requirements of the road or in deficit to cover in full the specified rotational length. For instance, a 2nd class metalled road may have the best of stone available for metal at lesser lead, the soil for the subgrade may be of a stable character, the water for consolidation close by and the lead for fuel short and, above all, the intensity of traffic meagre. The frequency of renewal, in such a case, is naturally very low and the maintenance grant proves to be in excess of the requirements If the conditions stated above are reversed, the frequency of renewal is at once increased and the maintenance grant falls short to cover the specified rotational length. The road deteriorates and can only be brought back to the standard under special repair estimate. This process is recurring. To

remove this anomaly, the maintenance grants for roads should be determined on a rational basis. What this rational basis can be might be described as follows :—

The entire length of the road should be split up into sections having different intensities of traffic. An estimate should be framed for the entire reconstruction of each section. With due regard to the quality of metal and the intensity of traffic upon the section, the rotational period for the renewal of surfacing should be fixed by observing the behaviour of these or similar stretches. The total amount of the reconstruction estimate divided by the rotational period will give the average grant per annum per mile for the section. Thus the total grant which will maintain the surfacing efficiently for the entire length of the road can be arrived at. To this may be added the provision for patch repairs, blindage, repairs to masonry works, and white-washing of mile, furlong, boundary, curve, and guard stones.

This Rational Basis of fixing the maintenance grant for roads calls for the rationalisation of the system of the letting out of contracts for the maintenance of roads. The annual letting out of the contracts causes delay in the starting and completion of work. Instead, if the contracts are let out for a section for the full rotational period, the timely completion of work would be guaranteed, the contractor will feel secure and tender lower rates, the labour would be paid better wages in view of the long range programme and the "tip and run" tactics of the contractor would become absolute anathema. It is high time that the Indian Roads Congress takes up these questions and lays down the general outlines for the organisation and administration of roads under maintenance.

As regards the formula given by the Rao Bahadur at the end of his paper, I am afraid the rotational period and the intensity of traffic fixed by him are both low. First of all, it is problematical whether reconstruction with $1\frac{1}{2}$ in. new metal is really effective. I have had some experience of it and my own impression is that by mixing the "live" metal with "dead" metal, the efficiency of new metal is wasted. Any thickness of renewal coat less than 3 inches is next to useless.

The formula given by him was tested on two roads of H.E.H. the Nizam's P.W.D. where renewals are undertaken with 3 inch coats. The result is as follows :—

AURANGABAD-JALGAON ROAD.

Daily intensity of traffic = 254 tons.
Cost of metal (hard trap) = *B.G. Rs. 7.7- per 100 cu. ft.

$$A = \left(C \frac{T}{15} + 12\right) + \frac{T}{5} + 50$$
$$= 7.7 \times \frac{254}{15} + 12 + \frac{254}{5} + 50$$
$$= \text{B.G. Rs. } 243/\text{- or O.S. Rs. } 284/\text{-}$$

The maintenance grant per mile is O.S. Rs. 540/- assuming $\frac{2}{3}$ of it for

* B.G. Rs. 100/-=O.S. Rs. 116/10/8.

reconstruction and ⅓rd for other items, the grant for 1½ inch coat would be

$\frac{1}{3}(540 \times \frac{2}{3}) + (540 \times \frac{1}{3})$
or O.S. Rs. 360/- or B.G Rs 300/-

HYDERABAD-SHOLAPUR ROAD.

Daily intensity of traffic = 1264 tons.
Cost of metal (hard granite) = B G Rs 11 5 per 100 cu ft

For the sake of argument, maximum intensity of traffic has been assumed as 800 tons in place of the actual 1264 tons

$$A = \left(C\frac{T}{15} + 12\right) + \frac{T}{5} + 50$$
$$= \left(11.5 \times \frac{800}{15} + 12\right) + \frac{800}{5} + 50$$
$$= \text{B. G Rs. } 835/- \text{ or O. S. Rs. } 974/-$$

The maintenance grant per mile is O S. Rs 670/- The allowance for 1½ inch coat, as above, works out as O S. Rs. 147/-. In one case the result is in deficit by 21 per cent and in the other in excess by 118 per cent

It is not for me to say what is the standard of maintenance of roads in Hyderabad State Those of the gentlemen present who have had occasion to travel along these roads will please speak out

Mr. J T. Mehta (Bhavnagar) :—The paper is very interesting and in these days when cuts are made even on inadequate maintenance grants, it is well to emphasise certain important points in maintenance of Roads, which is generally left to subordinates to look after. As stated in paragraph 7, proper consolidation is important It was pointed out at the meeting of the 1st Indian Roads Congress by Mr G.A M. Brown that in N W.F Province, roads stood up to heavy bullock cart traffic due to the excellent quality of stone and proper consolidation The author also arrives at the fact that 600 cu ft. to 800 cu ft. of hard metal can be properly consolidated per day by a power roller, whereas the Bombay P.W.D. Hand Book still maintains in the notes for the guidance of subordinate staff that one furlong of metal 16 ft wide 3 in. thick should be consolidated by a power roller per day.

Another point is about the water used in the earlier stages of consolidation. The author rightly points out that water should be just sufficient to keep the sub-grade moist whereas in the notes by the Bombay P W.D. free flooding with water is advised I think such obsolete specification should be withdrawn

As regards para. 4, I have seen on this side, soft weathered and decomposed metal being collected when good hard basalt stone metal was available at twice the price. The cost of consolidating the latter would have been 1.6 times that for the former or if 2 in of hard metal be used for 3 in of soft metal the cost would have been equal. It certainly is false economy to have more miles resurfaced with such weathered and soft metal.

Road maintenance grants in our State are distributed equally over several miles of a road. The traffic intensity on a road near urban areas is naturally high and it is surely a sound principle to distribute the grants on traffic basis.

Lastly in para. 9 the author says that it is false economy to dispense with the services of gang coolies in order to renew a great number of furlongs, but the percentage of allotment to be used for such purposes is not mentioned and it rather appears that the tendency is more to fritter away expenses on ordinary repairs Whatever percentage is set aside for ordinary maintenance work should be added to the annual renewal cost for arriving at the proper allotment per mile, which is generally not done. Instead a lump sum of Rs 100/- to Rs 200/- is added for ordinary maintenance which gives erroneous results.

Mr. A. Lakshminarayana Rao (Author) :—

Reply to Mr. J.T Mehta (Bhavnagar) :—

I agree with Mr. Mehta that steam road roller cannot consolidate efficiently one furlong of metal 16 ft wide and 3 ins. thick in a day.

With regard to the suggestion that a particular percentage be set aside for gang coolies, it has to be stated that gang coolies have to be paid on out-turn and should be entrusted with the following works : –

(1) Patch repairs to metalled surface.

(2) Closing gullies on the sides of the road caused by monsoon.

(3) Clearing drains and culverts.

(4) Blinding the road surface with gravel or gravelly earth when it is laid bare by winds

(5) Miscellaneous works of a petty nature.

The percentage of expenditure that can be incurred on gang coolies depends on the allotment that is given to roads. . Where the allotments are low and not proportionate to the traffic requirements, the road engineer has to cut his coat according to the cloth and to adjust his allotment so that gang coolies may be maintained at least during the rainy season and essential work may be done.

Reply to Mr M.A. Mirza, Hyderabad (Deccan):—

I thank Mr. Mirza for the compliment paid to me and agree with him that allotments to roads should be fixed on a Rational basis.

With reference to his doubts regarding the efficacy of 1½ in. renewals, I have to state that I got thousands of furlongs renewed successfully with 1½ in renewals but the specification for picking should be on the following lines:—

(1) Pick the road surface 2 ins. deep thoroughly.

(2) Remove the picked up stuff over the inner berms.

(3) Repick the surface ½ to 1 inch.

(4) Section the surface to the required cambre.

(5) From the picked up stuff thrown on the berms collect all metal over ½ in. size by hand.

(6) Spread on the picked road
(7) Hand pack to the required cambre.
(8) Spread new metal over the surface formed by process in the previous item.
(9) Then begin the rolling.

The new and old metal is found to be at least 2½ in. thick on the average in many cases and the consolidation then becomes one of a layer of 2½ inches Where the metal is good the picking sometimes gives 1½ inch layer of metal and the consolidation then becomes one of a layer of 3 inches.

The formula for allotments :—

I am sorry the printers' mistake has given results wide of the mark The bracket has been put before 'C' which it should have been after 'C'. Regarding Hyderabad-Sholapur Road, it must be stated that if a road with 1264 tons of traffic per diem is maintained in an efficient state with an allotment of O.S Rs 670 or B G Rs. 574/- it is a matter for congratulation to the officers concerned A study of the relative proportion of pneumatic tyred traffic and iron tyred traffic may perhaps reveal much information for study The standard aimed at may be different.

I must, however, mention that the formula is an empirical one, not intended to be mathematically accurate but to give rough results for general guidance in fixing allotments.

PAPER NO. H—1943.

AN ABSTRACT* OF PAPER ON A SUBMERSIBLE BRIDGE OVER THE UJH RIVER IN JAMMU PROVINCE

BY

MR. S. B. TAYABJI, I.S.E., (RETIRED), A.M.I.C.E., M.I.E. (INDIA),
Chief Engineer, Jammu & Kashmir State, Srinagar.

The Ujh river crosses the main road connecting Jammu, the winter Headquarters of the Jammu and Kashmir Government, and Kathua, an important town. It is at present unbridged. The road runs in a submontane track and though there are several other unbridged streams, crossing this important road, this river causes the longest interruption holding up traffic for a continuous period of over three months from the middle of July. The catchment area at the site of the crossing, which is about 7 miles to the south west of Kathua, is estimated to be 376 square miles with a calculated maximum flood discharge of about 26,000 cubic feet per second. The river here divides itself into four branches, separated by stretches of high mounds. These branches do not shift their courses more than a few score of feet in any particular season.

2. High level bridges were considered, but given up as prohibitive, the estimated cost being several lakhs even at pre-war rates A low crossing was, however, considered sufficient, as high floods are only for short periods. The present design is for a submersible bridge of reinforced concrete with spans of 20 feet clear and 23 ft centre to centre of piers. The deck level is kept two feet below the normal high flood level, such as occurs only for a few days in a year. There are 34 spans of 4 sets of 10,8,9 and 7 spans over the different branches The details of the superstructure and substructure are given in the plates attached. The superstructure consists of Reinforced concrete slabs which are continuous over 3 and 4 spans. These slabs are 12½ inches thick and designed for an 8-ton roller (10 tons in working trim) with an impact of 25 per cent. The clear width of the roadway is 12 feet between guard rails. The noses of the slab, both upstream and downstream, are streamlined to cause minimum obstruction to the flood. Reinforced concrete guard posts are provided over the piers and midway between them with holes in them to take in guard rails in the fair season.

3. The foundations adopted for this bridge are peculiar and deserve special mention. The foundations are proposed to be taken to six feet below the lowest bed, which is about a foot below the expected scour level. Heavy springs were also expected and as large pumps were not readily available, it was proposed to provide "Club Feet" to about 6 feet below the foundation level for holding down the piers in the event of the scour extending locally to greater depths.

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* The original paper is available in the office of the Indian Roads Congress for reference.

The "Club Feet" are to consist of reinforced concrete cylinders 18 inches in diameter terminating in 3 feet spherical bulbs, the stems being 3 feet long The total length of this "Club Feet" will be 6 feet. There are to be two in each pier, pre-cast and lowered into pits dug below the bottom of the pier foundations They might also be cast hollow and filled in with cement concrete after they are lowered into position, the outside being packed round with cement concrete and boulders The reinforcement of stems will be let into the slab to be laid over these at the bottom of the pier foundations. The details are shown in plate No 2. The Author considers that the weight of the pier would thus be taken up by the "Club Feet", were the boulders ever get displaced to such depth.

4. The work is reported to be in progress and so far the anticipated foundation difficulty referred to in the previous paragraph has not arisen By diverting the course of the branches during construction, it has been found possible to keep the foundation beds clear of water. In place of the proposed "Club Feet", therefore, plain cement concrete cylinders have been laid *in situ*. The details of the works so far executed are also shown in plate No. 2

5. Training works to confine the different branches to their present courses are also proposed The intervening spaces left between the series of openings are, however, so arranged as to admit of a similar series of openings of the same span lengths, should such a contingency arise at a later date.

6 The total cost of the bridge is estimated at Rs 1,14,500, which works to Rs 165 per running foot on the combined length of 692 feet between extreme ends of piers, and Rs 6.44 per square foot of the elevation between road level and the bottom of the foundations

Thursday—October 7th, 1943.

Mr. W. L. Murrell (Chairman):—I would call upon Mr. Tayabji to introduce his Paper "Submersible Bridge over the Ujh River in Jammu Province".

The above paper (pages 157, 158) was then taken as read.

Mr. K. S. Raghavachary (Simla):—This paper of a submersible bridge has many novel features and is therefore of interest. Due more to conservatism R. C. slab bridges are at present generally limited to spans of 15 ft. to 16 ft. though it is more economical to have this simple type for spans up to 25 ft. The clear span in this case is 20 ft. For the load for which it has been designed viz., a 10-ton roller with an impact of 25 per cent. only, the thickness of the slab works to only 12½ ins. In the case of submersible bridges, this is a special advantage, as the area of obstruction to flow is reduced to a minimum. Full calculations of the design had not been given even in the original paper. The following points seem to require some clarification :—

(1) In the case of the deck slab no extra reinforcement had been provided at the ends for taking up the negative bending moments which will be W. L./16.

(2) The slabs have not been anchored to the piers or the bed blocks. It is usual in bridges of the submersible type to anchor these against uplift, allowing sufficient play for expansion and contraction of the deck slab itself.

(3) In submersible bridges, it is necessary to reduce the obstruction to the flow of water to the minimum and even end curbs are generally avoided. In the present case the slabs are cup-shaped in cross section increasing the area of obstruction and water pressure. Also after every flow, there would be accumulation of silt and water in the road, making it slippery and risky, especially as there is no side railing. It is doubtful whether the drainage provided by the galvanized iron pipes in the centre of slab would be efficient. That would get choked up by silt and debris and may not function till they are cleared.

(4) The novel feature of the foundation is the "club feet". Precast concrete "club feet" were proposed but had not been carried out in execution, partly because there was no need, and mainly, probably, because it would have been impossible to place it in position unless special tackle is used as the weight of the "club feet" works to about 1½ tons.

(5) The masonry piers rest on a block of lime concrete 3ft. thick. The "club feet" portion alone is connected by R. C. slab 12 in. thick. The lime concrete cantilevers 5 ft. 9 in. from the end of the pile foundation. The total dead and live load works to nearly 100 tons and assuming it distributed uniformly over the 7 ft. width for the entire length. load

on 1ft. width of concrete works to 3 86 tons and the tensile stress is as much as 115 lbs. per square inch. This stress especially in lime concrete is far in excess of the permissible limit. It would have been much better to have provided an R C. slab over the club feet and the cantilever portion, also designing it for the total superimposed load. It would be of interest to know how this 3ft. slab foundation would be functioning.

Mr. Dildar Hussain, Hyderabad (Deccan):—A study of the cross section of the river crossing as given by the author reveals certain interesting facts. The stream, at the site of the crossing, breaks into four main channels, which, reading from the Kathua end, may be called No. 1, 2, 3 and 4 The following levels show the changes which have taken place in the bed levels in the course of 1 year:—

	New Bed levels	Previous Bed levels	Silting	Scour.
	1942	1941	+	—
Channel No 1.	88.58	85 90	2.68	—
—do— 2	90.83	95.95	—	5 12
—do— 3.	87.75	94.50	—	6.75
—do— 4	92.73	88.20	4.53	—

At the same time it would be interesting to see what changes have taken place in the bed widths of the channels

The following figures show the position :—

	1941.	1942	Expansion	Contraction.
Channel No 1.	200 ft	200 ft	—	—
—do— 2	405 ft.	100 } 205 ft.	—	200 ft.
—do— 3		105		
—do— 4.	310 ft	135 ft.	—	175 ft.
Total	915 ft.	540 ft.		

It is clear from the above figures that channels No. 1 and 4 have silted, whereas channels No. 2 and 3 have been scoured to depths varying from 5 to 7 feet nearly, with the resultant contraction in the regime.

The author states that "the foundations are proposed to be taken to 6 feet below the lowest bed, which is about a foot below the expected scour level". It would have been interesting to know how the anticipated scour level was determined The above figures show that in the very first year, the scour in channel No 3 has exceeded the expectation of the author, and there is no guarantee that it may not be exceeded further in future, considering the fact that the author has assumed an extraordinarily low discharge of 26,000 cusecs from the catchment of 376 sq miles

The stream is said to be in the submountanic region, and "causes the longest interruption holding up traffic for a continuous period of over three months". If the discharge of 26,000 cusecs is assumed to be correct, then it gives the value of C=30½ in Dicken's formula and about

500 in Ryve's formula. These values would scarcely be applicable to a stream of the above description and small catchment. On the other hand, if we assume a modest value of C=1000 in Dicken's formula for the tract of the country described, the discharge works out to about 85,000 cusecs, or a little over thrice the designed discharge. The question is what would happen if a flood of this order were to occur.

The bridge consists of 34 vents of 20 ft. span with height of piers 13 ft. approximately. For a discharge of 26,000 cusecs, as assumed, the velocity works out to be about 3 ft. per second ignoring afflux, and if a discharge of the order of 85,000 cusecs were to come, the velocity would rise to about 10 ft. per second, in which case there is bound to be very considerable scour in the channel much beyond what has already taken place. It would therefore seem that the depth of foundation viz. 6 feet is inadequate for its safety.

The nature of soil in the foundations is not mentioned in the summary of the paper, but from para. 1 on page 158 it appears that the concrete block supporting the pier is made to rest on two reinforced concrete pre-cast cylinders, each 4 ft. diameter, which have been lowered into pits dug below the bottom of the pier foundations, the outside being packed round with cement concrete and boulders. The Author also considers that the weight of the pier would be taken up by the "club feet" in case the boulder packing got displaced.

The design of "Club feet" foundation which may more aptly be termed a "Wall-plug" type, is very peculiar. It means that statically the load of the pier is being distributed over two pin points, as against the usual and rational method of uniformly distributing the load on the soil through a concrete block. What the rationale of this design is not clear. One thing is obvious that if the bed were to get scoured the upper concrete block would stand unsupported, and the tensile stress caused by the overhang of the pier would lead to cracks both in the block as well as in the pier masonry.

The bridge decking has been given the shape of a saucer, and this is said to be due to considerations of stream-lining the ends to cause minimum obstruction to the flood. It is seen that by so doing the top of the kerb is raised by about a foot above the road level which gives a total uplift head of 1 ft.+12½ inches or say 2 ft. [62.5 lbs. x 2=125 lbs.], against 12½ inches depth of reinforced concrete slab=156.25lbs. Thus the margin between the static load of the slab, and the uplift pressure has been considerably narrowed down. Should there be any impact on the edge of the slab due to any trees brought down in flood, there is the possibility of conditions arising which might tend to the floatation of the slab. It would therefore have been advisable to have anchored the slab into the masonry of the piers.

The Author states that reinforced concrete guard posts have also been provided over the piers and on the slab. In the presence of the concrete posts, the raising of the slab ends merely for stream lining effects was really not necessary. It would have been sufficient if the bottom edge of the slab had been given a bell-mouth curve to increase the coefficient of discharge.

(3) **Rai Saheb S.K. Ghosh (Bihar)** suggested that a Discharge Sub-Committee might be set up to go into the matter of maximum flood discharges.

Mr Abdul Aziz (Punjab) :—In para 1 of the Abstract, it is mentioned that the catchment area at the site of the site of the crossing is 376 sq. miles, and that the maximum flood discharge has been calculated to be about 26,000 cusecs The catchment area is partly hilly and partly sub-montane. This calculated discharge appears to be rather on the low side. The various formulae adopted by different authorities, and the discharges arrived at by using these, in this particular case are given below.

(a) M. E. S. Formula for North West Frontier rivers, for catchments from 9 5 to 12,000 square miles—[page 42 of the M. E S Handbook Vol. III (Roads) 1925 Edn.]

$Q = 2100\,M^{0.5}$

$= 40{,}710$ cusecs.

(b) Dickens Formula.

$Q = CM^{0.75}$

$= 70{,}460$ cusecs, (with an average value of $C = 825$)

(c) Ryve's Formula (usually used in Madras Province)

$Q = CM^{\frac{2}{3}}$

$= 35{,}170$ cusecs, ($C = 675$ for limited areas near hills)

(d) Beale's Discharge Curve at page 615 of Bombay P. W. D Handbook (1931 Edn) gives a maximum discharge

$Q = 86{,}680$ cusecs.

(e) *Whitting's Discharge Curve, (Bombay P W. D. Handbook)* gives

$Q = 83{,}040$ cusecs

(f) The formula quoted on page 299 of these proceedings, by Mr. Farhatullah in his paper on "Masonry Arch Bridge across the Krishna" is

$Q = CM^{0.92 - \frac{1}{14}\log M}$

$= 1{,}33{,}690$ cusecs (with $C = 1700$ for hill catchments)

My own experience on the new bridges recently constructed in the sub-montane area in the North West of the Punjab is that an average between the figures got by using Dicken's formula (b) above, and Whitting's curve, (e) above, is the more correct figure to adopt, as this nearly tallies with the actual run-off calculated with the highest Flood Level experienced. The point I wish to bring to the notice of the Roads Congress is that, as will be seen from the above results, the various formulae give very divergent figures In the above case, they vary from 35,000 cusecs to 133,690 cusecs, whereas the approximate correct figure should be about 80,000 cusecs. It is suggested that data should be collected by the various road, rail and irrigation authorities by actually observing the high flood marks on suitably selected sites on Nullahs and rivers, close to the existing structures, and the results so obtained should be co-ordinated for reference in definite areas of the various provinces

Mr. Lokanatha Mydaliar (Madras):—Talking generally of submersible bridges, I do not know if you will all share with me my distrust of this kind of bridge which is neither fish nor fowl. As far as possible, we may do well to avoid this type But considering that many bridges which we build as high level bridges, become submersible ones, when the calculations of the designing Engineer are exceeded by *Nature*, we may tolerate the bridge, intended and designed to be a submersible bridge. I stress on this point that it will be a fallacious gain on the road-rupeeratio if a submersible bridge is preferred to a high level bridge for the sake of a little saving in the cost, as it will not do to neglect the convenience factor which has a place in the ratio

When we deal with an irrigation canal which for some reasons has also to serve as a drainage channel, there is a good excuse for a submersible bridge. In such a case, smaller vents are indicated to limit the depth of the covering slab, and therefore the obstruction.

There is one point noticeable in the design, *viz.*, the want of anchorage of the R. C. Covering slab to the masonry of the piers and abutments. In the case of submersible bridges, this anchorage is all the more necessary than in the case of cause-ways and irish bridges, to counteract (1) the loss of weight of the slab due to buoyancy, (2) the tilting forces resulting from eddies, and currents, (3) the disturbing forces due to debris or trees floating down the stream. The slab in the submersible bridge is nearer the plane of maximum velocity than in cause-ways and so needs the anchorage more. The anchorage may be by means of mild steel rods of suitable size, not less than 1.5 in in diameter, led from the foundations of the pier upwards into the R. C. Slab, encased in cement mortar or concrete. In the case of cutstone or precast concrete covering slabs, the ends of the adjoining slabs can be connected by a dowel.

The curbs need to have long weep holes to wash away the silting which deposits when the flood subsides, after overflow over the submerged portion. By the way, this arrangement will serve well for all bridge parapets, to prevent the accumulation of dust brought by winds.
The boat-like shape, if anything, may induce the slab to *think* that it is a boat, and so to float away!

Mr. F.F. Fergusson (Jodhpur) :—Several of the previous speakers have suggested the setting up of a Sub-Committee to obtain data on flood discharges of rivers and one speaker gave a list of formulae which he used, to check the discharge to be expected from the catchment areas. Neither in the suggestions for the setting up of the Sub-Committee nor in the list of formulae quoted was there any reference to the immense amount of work done on river discharges by Mr. C.C. Inglis and his colleagues of the Central Irrigation and Hydrodynamic Research Institute at Khadakvasla (Poona).

The omission of any such reference is probably due to the fact that Road Engineers are not generally in touch with what is being done by Irrigation Engineers and there is therefore some danger of overlapping and wasted effort if the proposed Sub-Committee were to be set up without first establishing contact with the Research Institute and benefiting by the experience gained in this work since its inception.

There is not the least doubt that the proposed Sub-Committee could do work of very great value, especially if previous contact were made with the Research Institute in order to ensure that uniform procedure in the collection and interpretation of data were followed, and that data obtained and properly correlated were made available to others interested

A considerable amount of river discharge and flood data has been accumulated and is being added to annually by various authorities throughout the country such as the administrations in charge of hydro electric power installations, railways, municipal and other water supplies, and irrigation, this data is not readily available to every one interested and it is doubtful whether any attempt has been made to standardise the methods employed in the collection of the data by these separate administrations or to correlate them so that an Engineer obtaining information from one source may be sure that it bears a scientific relation to that obtained elsewhere.

It is obvious, therefore, that it is essential for the proposed Sub-Committee to start its labours on the right lines by making use of the experience gained by any other research body which is willing to lend its council, if it is to do work, which will command the respect of other Engineers and be worthy of the Indian Roads Congress

Mr. U. J. Bhatt (Bhavnagar) :—I have risen to endorse the good suggestion just made to compile flood-discharge data in various parts of the country The usual practice is to follow various empirical formulae, but they have been found to give different results in different regions, because at best, they are merely indicative of approximate discharges. The current practice in U. S. A and other countries is to work out the discharges, based on rational methods, depending upon the hydrology of the region. These methods take into account various characteristics such as nature of terrain, ground slope, forestation, size and shape of catchment, and last but not the least, the intensity of precipitation.

In Bhavnagar, we have started collecting the data of flood discharges by rational methods, and we have installed automatic recording rain gauges. As this forms the pre-requisite, may I suggest, that the Provincial Government, and progressive Indian States may start installing such automatic rain gauges in catchments within their jurisdiction. I might like to strike a note of warning in this connection, regarding the scale of these automatic recording instruments. The scale should be such as to permit reading accurately the intensity of rainfall over short duration i. e. at least over periods of 10 and 20 minutes. This will go a long way in interpreting, nearer to reality, the flood discharges, by the rational methods.

CORRESPONDENCE.

Mr. Mohammed Ahmed Mirza, Hyderabad (Deccan) :—Merely an abstract of paper on a submersible bridge over the Ujh River in Jammu Province has been published and circulated among the members for discussion. Since the abstract is too concise, I am not sure whether any comments can be considered fair to its learned author, Mr. S B Tayabji.

Therefore, with due apologies to Mr. Tayabji I am making the following comments more with a view to elucidation of the points not clear to me and, at the same time, to seek enlightenment of a new theory he has propounded. I trust he will accept my comments in a spirit of charity and goodwill.

The drainage area of the stream at the point of crossing is said to be 376 sq. miles and the maximum flood discharge is estimated as 26,000 cusecs This appears to be a good deal on the low side. It is true that, on account of the varying conditions of rainfall and the physical features of the catchment area, a closer approximation is obtained by resorting to the cross-sectional area method, provided the H.F.L. is correctly determined, but the empirical formulae for determining the maximum intensity of flood discharge ranging from a unit discharge of 750 to 2,000 cusecs do certainly afford a guide to conditions that may be obtaining. In the much abused formula of Dickens, if the unit discharge is assumed as 850 cusecs, the maximum flood discharge at the point of crossing works out as 72,590 cusecs. I am stressing this point as it has a bearing upon my subsequent observation.

The Cross Section of the river shows that it is made up of a number of channels, and the bed levels, previous and present, distinctly prove that the regime is unstable. Therefore, the site can be considered to be unsuitable for any sort of bridge, whether submersible or insubmersible. The paper is silent as to why such a position has been considered obligatory.

So far as I know, the submersible bridges are an innovation in India. Like many other inventions, their conception is the result of pressing necessity. Although their principles of design are still unassessed and, perhaps, greatly disputed, a time will come when they would be the order of the day in tropical and sub-tropical countries. The C.P. is, probably, the only province that can claim a number of submersible bridges to its credit and some of them across the major rivers. From the experience obtained from them and elsewhere, it will not be wrong to surmise that what is of utmost importance is that the foundations should rest upon rock preferably, or within a soil bordering upon rock to counteract the tendency for scour. The design of the sections constituting the structure is, usually, no different from that of an all-weather bridge. By studying the plan of the Ujh Submersible Bridge, the obvious thing that strikes one is the unstability of the foundations. An attempt appears to have been made to safeguard against scour by the introduction of the "Club Feet" rounded at the bottom or made flat. This device, in my opinion, is a source of weakness rather than strength. From the constructional point of view the insertion of "Club Feet" must disturb the virgin compactness of the surrounding soil resulting in surfaces of two different resistances for the 3 ft. concrete bedding block of the piers. Under the circumstances, it is not unreasonable to suppose that the entire superimposed load shall be borne by the two "Club Feet" and, if this is so, the following defects in the design are obvious :—

(1) The intensity of pressure on the soil at the bottom of the "Club Feet" will be 5.6 tons per sq. ft. in the case of flat bottom and 9.70 tons per sq. ft. in the case of hemispherical terminus ;

(2) More serious drawback would be the overhang of the bedding block on either side of the "Club Feet" which will act as a cantilever and, since it is not reinforced, the pier masonry at the outer edges of the "Club Feet" must shear.

I have hinted, at the commencement of my remarks, about the maximum flood discharge as having been assumed too low. If the discharge happens to be of a higher order and the choking up of the vents by the moving silt great, the depth of flow over the bridge must necessarily be great. The under and over currents must equalise their potential by the dissipation of excess energy. Therefore the down-stream bed cannot remain immune to the disturbing element of scour with its attendant dangers.

Mr S.B Tayabji (Author):—I feel grateful to Mr Mirza for his criticism and also to the other members who have spoken.

The discharge of 26,000 cusecs was worked out from cross sections for ordinary high flood levels. It, therefore, represents the normal and not the maximum high flood discharge.

The whole idea of selecting the site where the river spreads out in this manner, or rather of taking the existing crossing as it is, and adapting the design to it, is to save cost, and the assumption is that the design. is justified by an ample margin of safety. There is no rock available for foundation anywhere near. A full size bridge would have to be deeply and expensively founded. In the design which has been adopted the foundation is taken just deep enough to be ordinarily safe against undermining by scour. The whole of the excavation for the main part of the pier foundation is in gravel and boulders, which get more and solidly locked together as we go deeper down. There is no silt. Sand is deposited only on the high mounds and the banks. Ordinarily, it is not expected that the foundation will scour below the bottom of the piers. The "Club Feet" are provided merely as an insurance, and it is claimed that the device is cheap and is likely to prove adequate even in quite extraordinary high floods or when local scour may occur during the course of the flood under piers. It is known that in times of high flood the gravel and boulders in the bed move down but that on the flood subsiding, the material is deposited again in a manner similar to the deposition prior to the arrival of the flood. It may thus happen that in extreme flood conditions, portions of certain piers may be temporarily suspended on the moving rolling mass of flood water and gravel and boulders. It is confidently expected that well constructed masonry will stand up to such conditions without seriously cracking and that if there are 2 well-placed supports to take the strain, such as the "Club Feet", even the unreinforced stone masonry should do the job of bridging over the gap and cantilever. Actually, there is a fairly heavily reinforced cement concrete slab provided over the "the Club Feet" and with the added strength provided by it there should not be much fear of the masonry collapsing.

During the monsoon of 1942 the foundations of a large multi-span arched super-passage (drainage syphon) on the Ranbir Canal near Jammu got scoured away in a high flood. The foundations rested upon gravel

and boulders. On the subsidence of the flood, the piers of 2 spans were found hanging in the air for considerable lengths, but no hair crack appeared in the old masonry which was brick in lime built some 40 years ago. The necessary repairs were carried out by underpinning, in considerable fear and trepidation. If in such case "Club Feet" had been provided, there need have been no fear at all.

Then, look at the difference in cost. We shall be spending about 1.15 lakhs only in bridging a major nallah, where an ordinary bridge would cost 7 lakhs in these days, 4 lakhs in ordinary times. Supposing after 10 years a heavy flood does carry away 3 out of the 34 spans, the damage can be repaired with an expenditure of Rs. 10,000/-, a sum which may be required periodically in safeguarding the approaches to a large and expensive bridge or in re-painting it. No loss of life will occur in such mishap since no traffic can pass in high flood. The road is katcha and is not passable in heavy rain. There are other numerous large and broad nallas which present serious obstacle to traffic and if a cheap and reasonably safe design can be evolved it will be feasible to treat them similarly. The only alternative is to let things alone. It is not feasible to provide first class crossings on all of them.

I would like to mention that, before this design was adopted, enquiries were made of the North-West Frontier Province where an interesting constricted bridge had been lately built. It was learnt that on the Hazara Trunk Road, the bridge on the Chamba Nallah had been constructed with a very much constricted water-way. The cost of a Vibro Pile Bridge over the whole width of the nallah would have been Rs. 90,000/-. The length of the bridge would be 600 ft. The maximum flood discharges of the 2 branches of the nallah which meet just above the site were calculated to total some 60,000 to 78,000 cusecs But the ordinary flood discharge was estimated at 10,000 cusecs only. It was decided to provide for a discharge of 10,000 cusecs only. The approach embankments were left katcha and so low that when the flood exceeded 10,000 cusecs they would be topped. (At the Ujh River it will be noted that all the intermediate mounds between the separate bridges will be topped in heavy floods). It was anticipated that in high floods the whole width of the river would be available for taking the discharge, the bridge standing as an island.

The Vibro piles were driven to such a depth that they can safely withstand *normal* maximum flood. To provide against damage by scour extending to a greater depth whilst the katcha side embankments were being cut away by the force of the flood, the floor of the bridge site was covered with stone in wire tiangers which was expected to curb the scour for a sufficiently long time. The bridge was completed in 1939 at a cost of Rs. 35,000/- thereby making a saving of Rs. 55,000/- over the original estimate of Rs. 90,000/. It was calculated that the interest on the capital saved in 1 year would more than re-pay for the complete reconstruction of the approach embankments.

At the Ujh River, we are of course providing both for a constricted water-way and for sumergence.

The progress on the bridge was unduly delayed last year by frequent floods. It should be possible to finish it in the coming cold weather.

It will certainly be interesting to watch the effects of the yearly high floods on the structure. Personally, I consider that the risk of scour has been provided against to an adequate extent.

In connection with the apprehensions that have been expressed of unduly disturbing the bottom of the foundation in the process of laying the "Club Feet" I confess I am not able to share the feeling. The stuff is hard boulders compacted together. The foundation for the whole of the pier base is first excavated and then the 2 pits are dug for the wells or the " Club Feet". Actually, the stuff there is quite hard. When the excavation can be done in the dry, it will be filled in with well rammed cement concrete faced with large stones and no soft spots need be left in the filling. If water is met with, then the reinforced concrete "Club Feet" can be inserted and packed round with large stones and gravel and some lean cement concrete can be laid and rammed round the stems. Over the whole base of the pier and the tops of the stems of the "Club Feet" the concrete of the pier foundation can be laid and rammed down. The scour is not ordinarily expected to extend to the bottom of the foundations and the disturbed material may be expected to get locked together and consolidated with the lapse of time

The suggestion to provide openings in the raised sides of the slabs to prevent accumulation of sand is a good one. But we have to keep the design as cheap and simple as possible

The drainage holes in the bottom of the slab can be kept large enough and then I do not anticipate any serious trouble from the accumulation of sand. Anyhow there are long stretches of the road where sand piles up and a little extra bit of it on the bridge will not cause serious worry.

The work has been held up by unseasonal floods and only a short length has been executed. Making the slabs continuous for 3 spans provided for a heavy single length of slab that must be lifted by the floods to cause damage, but I shall pass on to the State Engineers the suggestion to anchor down the slab to the piers

The shape of the ends is designed to present a stream line face against the force of the flood and bell-mouths for entrance and exit. This will reduce shock. A similar design was adopted for a 3 span bridge over the Neil Nalla which is a steep torrent The bridge was made 3 years ago There the slab has been anchored down to the foundations; the very high velocity made it much more likely, than at the Ujh, that the flood would scour deep into the foundation. The bridge has been topped by several floods by several feet and has stood perfectly well. At that site a heavy submersible bridge was adopted in preference to a high level bridge because of the much greater danger to the latter from extraordinary high floods

PAPER NO. I—1943.

REVISED SPECIFICATIONS FOR BITUMINOUS ROADS IN THE PUNJAB

BY

ABDUL AZIZ, B.A., M.B.E.,
Executive Engineer, Construction Division (Roads), Mianwali.

The object of this paper is to place before the Indian Roads Congress some interesting, speedy and economical Specifications adopted for the Construction of Certain Strategic Roads in the North West of the Punjab.

Preamble.

Early in the year 1941, the Government of India, Department of Communications decided in consultation with the General Staff Military that development of certain roads in the Punjab had become urgent from the point of view of Military Requirements for the Defence of Northern India during this Second Great World War. The Government of India asked the Punjab Government to immediately take in hand the construction work in anticipation of detailed estimates.

A Special Roads Construction Division was formed for building the bulk of these roads (about 300 miles)—which cover parts of four Districts on the North West of the Punjab in the Thal and Salts Range Areas. Except one road, i e. Khushab-Mianwali, on which the work had already been taken in hand by the Punjab Government, all the other roads were commenced without any detailed estimates or plans, and surveys and alignments had to be carried out side by side with the work of letting out contracts and making arrangements for Steam Road Rollers and other Plant essential for the execution of the works.

In this paper I will not touch upon other aspects of the works such as organisation, survey, alignment, construction of Bridges and Culverts, cause-ways etc , but confine my notes to the Specifications adopted for the building of the metalled width on these roads.

The question of selecting suitable Specifications loomed large as soon as the works were mooted. The watchword was "War-time speed, coupled with efficiency and economy". The areas in which the roads were to be built are difficult, dry, mostly barren, and thinly populated and part of the Mianwali-Bannu Road lies in the dangerous Trans-Indus area bordering on the North West Frontier Province in which the risk of kidnapping and attacks by tribal outlaws is always present. The roads had to be constructed through every type of soil—sandy, sandy loam, black cotton soil, clay; also in plain, badly broken, hilly and semi-hilly country. Acute scarcity of water even for drinking purposes and difficulty of transport of materials over the old difficult and steep tracks were the prominent considerations to be met with.

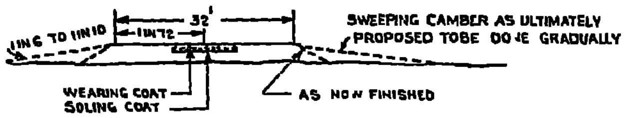
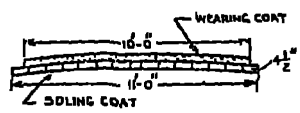
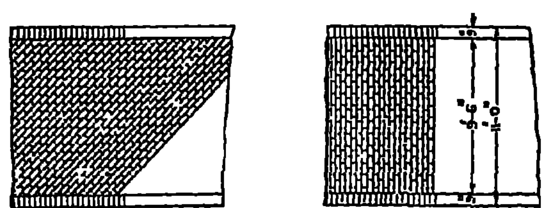


FIG 1



SECTION

FIG 2



PLAN

FIG 3

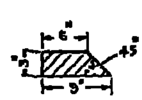


FIG 4

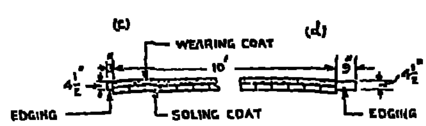


FIG.5

Formation and Sub-grade.

The Government of India wanted metalled and tarred roads single carriage-way, i.e. 10 feet wide. The total formation width has been kept 32 feet in plains and 24 feet in hills In the hilly and semi-hilly area, the formation levels were of course controlled by the design of alignments according to the ruling and maximum gradient fixed, but in plain country, the finished formation level was kept only about 9 inches above the surrounding ground except where there was a local depression, or water was known to collect, when the bank has been raised suitably. The low bank has the following advantages :—

(1) The soling coat is laid nearly directly on a firm sub-grade. The ponding and compaction of bank required to make it fit to receive soling coat was very doubtful as availability of water in such large quantities was considered to be very difficult and not possible without exorbitant expense and unreasonable delay. To follow the old peace-time practice of leaving the bank for ponding by rain during one monsoon season was out of question It was, however, very lucky that the winter of 1941-42 and summer of 1942, during which seasons most of the bank work was done and soling coat laid, had exceptionally heavy and long rains and consequently most of the formation received good ponding.

(2) Saving in time due to less quantity of earth-work having to be done, and consequently

(3) Saving in the number of labour required also.

Greater part of the labour required for the works had to be imported because apart from the reasons given above, young men in the area have gone to the Army, this being the famous Recruiting Area that forms the forearm of the 'Sword Arm of India.'

(4) Comparative ease and less expenditure with which a low bank can be given flat side slopes so as to minimise the danger to traffic even if a motor vehicle goes off the road; also the psychological advantage which one gets when driving on a low formation. (Fig. 1).

Soling Coat. General.

The sub-grade was then rolled, trenched and made fit to receive the soling coat.

In the Punjab the present day general practice for new construction has been to lay tightly :—

(i) $4\frac{1}{2}$ inches brick on edge soling coat or

(ii) 6 inches stone soling coat.

Of course in widening the old metalled width in stretches where the berms have been stabilised and are firm, the widening has been tried successfully without any soling coat and by using a 4 in. coat of metal only. The new edge of the widened strip is kept well proud of the old edge as settlement under traffic is seen to be quite marked.

Soling Coat on Strategic Roads.

In the construction of the Strategic Roads, the following thickness and types of soling coat have been used according to considerations of the availability of materials, nature of soil, cost and saving in time —

(1) 4½ inches brick on edge soling coat laid, diagonally, as well as laid square to the road—Length 32 miles.

The diagonally laid soling coat Fig 3 (a) is found to give better results than the square laid one Fig 3 (b) because of the better distribution of load in the former case, but on account of better progress that can be had by laying it square and the elimination of waste which occurs by cutting full size bricks for the end ones, the square laying was mostly followed.

When kilns are installed for road purposes, specially moulded end bricks (fig 4) can be conveniently burnt at no extra cost. This facilitates the laying of soling as well as avoids wastage of bricks. On these roads, however, there were only a few existing kilns and all the quantity of standard size bricks readily available in these, were purchased and used. Brick edging as shown in fig. 5 has also been laid in a few miles.

(2) 3 inches flat brick soling coat where the soil was considered good and subgrade firm—laid in 24 miles.

(3) 6 inches to 5 inches thick broken lime-stone or hard sand-stone or quartzite boulders laid in 186 miles.

(4) 3 inches thick lime-stone soling coat of 3 inches gauge, used in good clay soil. Apart from these, this small thickness of soling coat has been tried in a few slightly sandy miles—Length done 32 miles.

(5) In hill reaches where the road is in cutting and the subgrade is already hard and of stone or boulders, no soling coat has been used 4-inch wearing coat was laid direct on the hard subgrade which was of course thoroughly rolled with a Steam Road Roller and brought to proper grade and slope. Total length about 3 miles

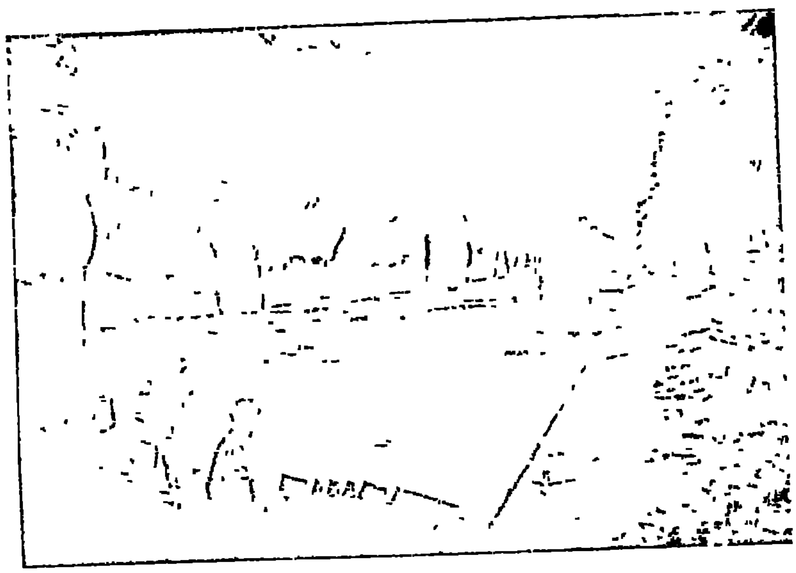
The leaner specifications (2) & (4) were adopted primarily

(a) for speed in construction, i.e. lesser quantity of material required to be carted, collected and laid, which took less time than if a thicker coat had to be given, and

(b) for economy in cost where the bricks or stone could be had only with very long and expensive leads.

It is yet to be seen as to how far the thin stone soling specification can be adopted in the future works. Although it is considered adequate for medium traffic of pneumatic tyred vehicles, it is doubtful if it will stand up under concentrated steel or wooden tyred bullock cart traffic

Showing use of Trolley Sprayer and the various spray operations. All the three coats can be seen in the picture.



Brick soling coat laid diagonally.

The fact that there were practically no bullock carts in the area in which the above specifications were proposed encouraged us to try the thin thickness of soling and it has so far (about one year) given no trouble and stood up satisfactorily under motor traffic.

Consolidating soling coat.

The soling coat in every mile was thoroughly consolidated with water by Steam Road Roller As is well known, the subsequent behaviour of the finished road surface depends to a large extent on the proper laying and consolidation of the foundations.

Quantity of water for consolidating soling.

The following figures showing the average quantity of water required for good consolidation might be of interest to the readers .—

		Gallons per mile of 11 ft. width.	Gallons per cu. ft
(1)	6 in stone soling coat, in good clay soil	43,000	$1\frac{1}{2}$ gallons
(2)	6 in. stone soling in sandy soil and sand dunes	65,000	$2\frac{1}{4}$,,
(3)	$4\frac{1}{2}$ in. brick soling in good soil	29,000	$1\frac{1}{4}$,,
(4)	$4\frac{1}{2}$ in brick soling in sandy soil.	40,000	$1\frac{3}{4}$,,

For 3 in. brick and 3 to 4 in. stone soling, the water required is about 60 to 75 per cent of the above quantities per mile

Consolidation of soling in sand.

Consolidation of soling coat in sandy tract was quite a ticklish job. It was found that a heavy (10 ton) roller sank and stuck badly if used directly on the soling from the commencement. To avoid this, the consolidation was started with a light 6 ton roller. The soling coat was first rolled lightly, dry and then gradually with water. When it became fairly firm, consolidation was completed with a heavy roller, till there was no movement under the wheels It is essential that the consolidation should be started from the ends towards the centre. Once the consolidation is properly done, it is found that even in sandy areas there is little settlement afterwards In fact the surface of the miles in the sandy stretch near Wan Bhachran on Mianwali-Khushab Road is among the best in respect of evenness and grade and no settlement or waviness has appeared although it is about 18 months that these miles were constructed and no subsequent surfacing coat had been given so far. During consolidation the soling coat sank from 6 inches to 9 inches. In local depressions extra stone was used (out of the 5 per cent balance kept while laying) instead of dismantling and relaying it after making up the subgrade. The former method gives definitely better results.

It may incidentally be mentioned that it is advantageous if the road formation *rides over or near* the top of the sand dunes instead of cutting *through them* as less obstruction is then experienced during sand storms due to sand blowing on to the road surface

Wearing coat and surfacing.

Till about the year 1934 the usual economical specification adopted for metalling and tarring in the Punjab was .—

(1) Consolidation of wearing coat stone as for ordinary 'Water bound-macadam' complete with earth blinding on top.

(2) Traffic was allowed for some time on the 'waterbound' surface and then two coats of tar applied at intervals after brushing and cleaning it with steel and fibre brushes

This method of construction is slow, as it takes a long time to complete the brushing with steel and fibre brushes before applying the first coat of binder. It is also tedious and expensive There is also wastage of bajri and blinding materials These set the Road Engineers experimenting and devising other cheap, efficient and quick specifications In recent years notable work has been done in this direction by our late Chief Engineer, Mr. S G Stubbs, I.S.E., O.B.E., and by Mr H.A Harris, I.S.E., Superintending Engineer who experimented and evolved improved specifications with the result that the old 'water-bound Specification' and tarring on the above lines is now practically out of date for new road construction in the Province.

Built-up-spray-Grout Specification.

Details of the specification are given in Appendix A

This was evolved by Mr. Harris after extensive trials and is considered to be most successful and suitable for general application The main feature of the specification is that tar is sprayed or grouted in with a mechanical sprayer over partially dry consolidated metal Advantages of this specification over the old one are —

(a) Quick progress in consolidation With good 'bandobast' about a furlong of road 10 ft wide can be done a day, whereas with 'water-bound' the progress is a little more than half of the above.

(b) No wastage of labour or blinding materials or any disturbance of the wearing coat metal which occurs in the case of 'ordinary water-bound-macadam' when the surface is brushed hard and cleaned to receive the first coat of binder

(c) The tendency to better binding between the metal and tar coats.

(d) A very much denser wearing coat than with ordinary water-bound-macadam

(e) As metal is laid in 2 or 3 layers and each layer hand-packed, the wearing coat is of a uniform compaction and the possibility of uneven settlement is reduced to the minimum.

(f) Less quantity of water required than for ordinary water-bound-macadam.

The real merit of this Specification however does not lie in the point that it requires less quantity of water than water-bound-macadam but in the fact that it provides for a much quicker and more homogeneous type of construction than water-bound-macadam and gives a fairly close proximation to a tar grout or a tar concrete at a very much reduced cost

Modified built-up-spray grout or semi-grout.

Later on the Built-up-Spray-Grout Specification was slightly modified and we might say that a compromise was made between the old 'Water-bound' and the 'Built-up-spray-grout' by doing about 80 per cent consolidation of the wearing coat stone *with water* as for old 'Water-bound' without putting in blinding on top. Consolidation was stopped when there was no noticeable movement under the roller and metal was fully interlocked, brought to camber and blinding from bottom had come up to about ¾ inch to ½ inch of the surface First coat of tar was sprayed when the surface was skin dry, grit spread, rolled in and consolidation completed by adding a little more water. This is called the 'Semi-grout Specification'.

This specification was extensively adopted on the construction of many miles of roads in Lyallpur District where the author happened to be in charge of these works and found the specification to be quite speedy and to give excellent results.

Specification for strategic roads 'Semi-grout' where water is available.

When the works on the Strategic Roads were started it was decided to adopt the 'Semi-grout' specification (**Appendix B**) for those miles where water could be had expediently and at reasonable expense, saving of time being the guiding factor. Supply by gravity from wells was impossible as the few that were near the roads had a limited supply The only alternative was to carry water from deep *nullah* beds or wells in certain reaches.

The problem thus was as to how to treat the miles where copious supplies of water could not be had for the wearing coat to follow the 'Semi-grout' Specification as laid down above A suitable and economical dry specification for wearing coat and tarring was thus considered necessary

Dry construction.

Elsewhere in the Province in a dry sandy tract a tar carpet with a seal coat of tar has been successfully laid. The same was considered for the dry miles on these roads also but this specification was not followed for reasons of the longer time required for the completion of the work. A mile done with tar carpet takes about 25-28 days to complete with one roller against an average 14-16 days required with 'Semi-grout' and 'Built-up-spray-grout' specifications. Also the plant required for mixing, placing, and dressing the premixed carpet could not be expected to be

arranged quickly for such large works during the war days when there was difficulty of supply There was great dearth of trained labour too in these backward areas for work at so many scattered places.

Built-up-spray-grout dry Specification.

It was therefore decided to try the 'Built-up-spray-grout' Specification omitting the use of water practically entirely and altering and increasing suitably the quantities of binder and grit in the various spray coats. The various operations for the 'Built-up-spray-grout-dry' are detailed in **Appendix C.** In this specification total binder of 68 lbs per 100 sq. ft is used for three sprays This is slightly more than the 'Semi-grout' where binder used is 57 lbs and grit 7 cu ft. per 100 sq ft The extra quantity of binder was found to be essential for grouting the dry metal.

4-inch Specification.

To start with, a 4 inch metal coat was used for the dry specification but it was found in actual working that when consolidation was carried on after spraying the first coat of tar, the metal kept on moving and rolling under the wheels and did not set fairly quickly. A 3 inch coat was found to give better results and the thickness of the wearing coat was subsequently reduced to 3 inches in all miles where dry specification was adopted (**Appendix 'D'**).

3 inch Specification.

The traffic in these areas is not expected to be heavy for some time and the bottom heavier coat of tar would have therefore little occasion to work up With this consideration the rate of spray in the first coat was reduced and second and third coats increased in certain miles, **Appendix 'E'.** It is hoped that with this the surface will stand up richer and better even with light traffic

Final dry 3 inch specification.

In the dry specification it is observed that although the thin earth cushion underneath the metal does help to give a bedding to the wearing coat to provide friction to prevent movement upto a certain extent, the tar acts for some time more as a lubricant than as a binder and the camber of the road does not remain intact when the roller is worked after the first spray coat. It is not possible to complete the consolidation immediately afterwards But after giving one or two rolls the surface has to be left for a night so that the tar becomes tacky and then the consolidation is completed and surface brought to proper camber next morning.

If there is rain just after rolling the wearing coat or the first coat (after spraying), most of the rain water soaks into the subgrade and when rolling is done afterwards, some unevenness does appear In such cases such waviness should be removed from the reserve metal kept for the purpose and not by removing and relaying the wearing coat The percentage of voids being much more in the surface with the

dry work than when 'Semi-grout' Specification is followed, more grit as given in the specifications is required to give a complete carpet over the wearing coat crust. A light shower of rain however does no harm but benefits the surface.

Comparative Statement of binder and grit.

Quantities of binder and grit used in the various spray coats of the different specifications are given in **Appendix 'F'.**

Mileage done with various specifications.

The following is the number of miles done in the Division with the various specifications.

Name of road.	Mileage treated with various specifications.					Remarks
	Semi-grout	Built-up-spray-grout (dry)				
	with 4 and 3 inches metal	With 4 inches metal	With 3 inches metal.	Dry (final) with 3 inches	Total Dry.	
1. Khushab-Mianwali Road ..	55*	—	—	—		*All done with 3 inch metal coat only except a few miles done with 4 inch
2. Mianwali-Musakhel-Talagang ..	35	9	1	2		
3 Dhok-Pathan-Talagang Road. ..	3	13	—	—		
4. Chakwal-Talagang Road. ..	1	23	—	3		
5. Khushab-Chakwal Road ..	20	28	12	6		
6. Mianwali-Kalabagh-Kurram Road.	56	2	3	5		
Total.	170	75	16	16	107.	
Grand Total					277 Miles.	

The various specifications are shown on the line plan **Appendix G.**

Aggregates, binder and grit used.

The bulk of binder employed was Road Tar No. 2. It was originally proposed to give the third spray coat with bitumen (Secony Asphalt Grade 105 or Spramex H. X.) in certain miles The material was obtained, but as the work had to be carried out in winter, bitumen was not found easy to work with and consequently, only a few miles could be treated with it.

Grit of various descriptions from local nullahs and quarries as was obtainable was collected and used.

Very hard quartzite gravel could be had at Mari Indus and it was used in a few miles where it could be collected economically and without delay Its wider use was not feasible due to restrictions on Railway Goods Traffic and delay in carriage to roads on long leads The cost would also have been very heavy.

Most of the grit used is nodular lime-stone gravel which is no doubt softer and is crushed more easily than the quartzite river gravel Care has therefore to be taken in rolling it lightly and not crushing it to powder under the wheels. It is experienced that lime-stone grit binds better for Ist and IInd spray coats and is good in the final seal coat for light traffic *roads where there is no steel tyre* bullock-cart traffic Under the steel tyre it quickly powders and forms a paste with the binder and the life of the surface-coat is consequently shortened.

Quantity of water used in wearing coat for semi-grout.

It might be of interest to the readers to know the quantity of water used in 'Semi-grout' work and the progress on various items of work per roller per day—the roller being 8 to 10 tons in weight —

Water requirements, per mile. 10 feet wide,

(a) 4 inch wearing coat—53,000 gallons or 3 gallons per cu. ft

(b) 3 inch wearing coat—44,000 gallons or 3¼ gallons per cu ft.

Quantity of water required for 'Semi-grout' is a little less than what it would be for the ordinary 'Water-bound-macadam'.

Water was carried in water lorries, in old tanks mounted on ordinary open trucks and in some cases on pack animals as well as on water carts.

Progress per roller per day.

The average progress per day per roller of average 8-10 tons weight and in fairly good order has been as follows —

Items.	Length in Furlongs.	Width in feet.
(a) Consolidation of stone soling coat ..	1 to 1¼	11
(b) Consolidation of brick soling coat 3 inches to 4½ inches.	1½ to 2	11
(c) Consolidation of wearing coat Built-up-spray-grout or Semi-grout ..	¾ to 1	10
(d) Surfacing Ist coat	2	10
(e) Surfacing II coat.	3	10
(f) Surfacing III coat	4	10

With good arrangement, one roller can give in a fortnight a mile of completed road (excluding soling coat consolidation)

The maximum progress attained has been about 30 per cent more than the above average figures In hilly reaches the progress on operations (a), (b) and (c) may be taken as 25 per cent less than the above averages

Costs.

There is no material difference in cost with the various specifications. Those finally adopted are nearly equally economical—the 'Semi-grout' being cheaper by about Rs. 500/- than the 'Built-up-spray-grout-dry'.

A comparative statement of cost of construction with the various specifications including the cost of soling coat and 22½ per cent average premium paid due to War conditions is given in **Appendices H (a) and H (b).**

Tools and plant.

Apart from the usual small tools and plant and templates, the chief plant used for the wearing coat and surfacing consisted of

(i) 8 to 12 ton Rollers for consolidation,

(ii) a few 6 tonners, and

(iii) boilers and sprayers.

It was realised right at the beginning of the works, that many rollers were required for carrying out such a heavy road programme during a short period. At the peak of works there were 51 rollers working in the Division. The rollers had come from all possible sources. The new Rollers purchased from Marshall & Sons through the Government of India have cost at an average Rs 20,000/- each. Hire charges for other rollers average Rs. 11/- per day per roller including the pay of Driver and Fireman.

Practically all spraying of binder on to the metalled surface has been done with the admirably handy and light outfit designed some years back by Mr. Harris, a description of which appeared on page 5 in the 'Indian Roads' for November, 1936 An illustration of the same is repeated as **Appendix I,** for ready reference of the Members A slight improvement which makes it easier to move about has been incorporated in the chassis of the trolley by introducing a swivel arrangement at the front. Also a double handle is usually used instead of the single wooden one illustrated. Two men thus work the semi-rotary pump. Pumps with ball-bearings are easier to operate and give better progress

A number of 320 gallon capacity boilers fitted with sprayers were also purchased from B. R. Herman Mohatta & Co. at Rs 2,000/- each. These boilers did not prove very useful for actual spraying and particularly for 'Built-up-spray-grout' work, because the narrow wheels of the boilers ploughed up the wearing coat and caused 1 inch to 2 inches deep furrows which disturbed the whole camber and longitudinal slopes. These deep

furrows could not be easily set right These boilers were used mainly for heating the binder As the number of boilers was not enough, road tar was heated along the roadside in half cut drums also In certain cases where the big boilers had to be used for spraying they were dragged alongside the metalled formation and a long flexible armour hose used for spraying on to the surface as illustrated in Fig 6

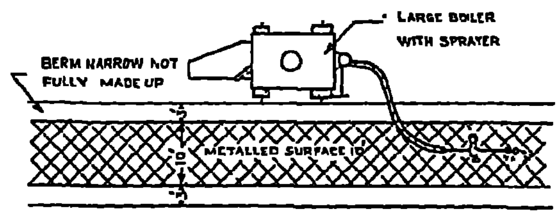


FIG 6

It is observed that a very useful combination of boiler and roller particularly for 'Built-up-grout-dry' specification would be Tandem Rollers with tar and bitumen boilers carried on tenders and fitted with sprayers instead of the usual 3 wheeled roller This has been actually tried on the construction of a runway by Mr. Harris and found to be a very convenient method

Behaviour of specification under traffic.

Various miles in the Division are now (May 1943) 6 to 18 months old. Traffic has not been heavy on every road, but some portions have taken Aerodrome Construction traffic up to an average of 500 to 1200 tons per 24 hours for the last 10 months, continuously without any subsequent renewal coat having been given on the new surface It will therefore appear fair to take the behaviour of the heavily trafficked miles as representative of the specifications used

Built-up-grout-dry.

The results obtained from this 'All dry' and economical specification have been above expectations. The 'Dry-grout' miles have taken equal traffic side by side with the 'Semi-grout' miles without any failure or signs of unravelling

It is however observed that as there is not enough blinding and denseness in the whole body of the wearing coat crust to start with, a greater part of the surfacing materials, i e., binder and bajri are worked down and wedged into the interstices of the metal Thus after some time the face of metal can be deciphered under the thin cover of surfacing coat that remains on top and bajri and binder have worked lower on its (metal) sides The wearing coat thus becomes denser, more homogeneous and more water-proof but the surface shows a dry appearance as compared with 'Semi-grout.'

Consequently the first subsequent surfacing coat has to be given earlier than with 'Semi-grout' after which there is expected to be practically no difference in the condition and life of the two surfaces.

With the rain water soaking into the wearing coat from the surface and sides during the first monsoons and with traffic wear, the 'Dry-grout' road is bound to show a little unevenness in the surface which is easily rectified by careful levelling and patching with premix bajri before giving the first subsequent coat Once the surface is properly repaired and the first subsequent coat is given, it will stay even and waterproof and there is no danger of any further settlement.

As the berms become firm and stabilised, soaking of water from the sides into the wearing coat is more or less eliminated.

'Semi-grout' specification.

In the 'Semi-grout' miles, about 80 to 90 per cent consolidation of wearing coat has been done as for ordinary water-bound, before spraying the first coat. The blinding has thus filled up all the interstices and the crust is compact. When the 1st spray coat is given, the blinding and binding material from the wearing coat has already come upto within 1/2"—3/4" of the surface. It is therefore seen that only a part of the grit and binder put into the 3 spray coats works down into the metal, and the balance forms an armour coat over the metal.

With traffic, part of the binder works upto the surface with the result that the semi-grout miles even as old as 12 months are showing excellent surface and richer than the 'Dry-grout' under similar conditions.

There are also practically no signs of any settlement in these miles although the monsoons of 1942 were exceptionally heavy for these areas.

Wearing coat with only 3-inch soling coat.

The readers might ask that if a 3" thick stone soling coat is found to be sufficient, why it was not more extensively adopted.

A thin stone soling coat as explained under the sub-head "Soling Coat on Strategic Roads" is not the established practice for new roads and the work done in this Division may be considered as an experiment on a large scale. Time will show whether the use of thin stone soling can be made more general. Personally I am very doubtful if it can stand upto bullock cart traffic although the miles done with 3 inch soling on Chakwal-Talagang Road have taken the heavy Aerodrome Lorry traffic very well.

With 3 inch stone soling coat, the thickness of wearing coat has been kept 4 inches throughout, because greater part of 1 inch of metal coat is used up in making up the surface of soling coat during its consolidation, and wearing coat thickness is left practically 3 inches.

The 3 inch soling coat gave lot of trouble during consolidation and after the rains. If the soil is slightly sandy (gauge of soling stone being only 3 inches) too much filler rises to the surface under the roller during consolidation and it keeps on moving like a flexible carpet, i.e. the 3 inches soling coat gets partly lost in the sub-grade. In black cotton type of soil, which is very hard when dry and slushy when wet, the 3 inches

soling coat can be consolidated fairly satisfactorily when there are no heavy rains, but it forms a sort of mud concrete if consolidation is tried soon after or during rains. 3 inch stone soling coat also showed more settlement and unevenness during consolidation and it took good deal of labour to set it right.

3 inch flat brick soling coat is however definitely better because it has a larger bearing surface and consequently its sinking in soft soil or its settlement is not so marked during consolidation.

Acknowledgment.

The writer gratefully acknowledges the valuable guidance and encouragement given from time to time by Mr. J B Vesugar, his late Superintending Engineer, and Mr. H. A Harris, the present one, during the execution of the above road works and further grateful thanks to the latter for his kind permission to draw upon his materials as and when necessary.

APPENDIX 'A'.

BUILT UP SPRAY GROUT SPECIFICATION WITH 4 INCH METALLING WEARING COAT BY MR. H. A. HARRIS, I. S. E.

—:-o-:—

1. A ¾ inch or 1 inch cushion of good clay earth shall be spread uniformly on the consolidated soling coat, thoroughly saturated and lightly raked.

2. 2 inch thick metal of 1½ inch to 2 inch gauge shall be closely and uniformly spread and hand-packed to proper camber over the earth cushion. The metal spread in this coat shall be from under stacks.

3. 8 per cent of free quarry screenings shall then be uniformly spread over the surface and washed down with water.

4. The remaining 2 inches thick of clean dry metal 1½ inch to 2 inch gauge shall then be uniformly spread over the metal already spread and particular care shall be taken to closely hand-pack it so that the carpet is quite even and dressed to the correct camber. Should any earth be observed on the metal during dry weather the surface may be sprinkled to wash down the earth.

5. The surface shall then be rolled lightly dry, starting from the sides and working towards the centre. Any depressions that appear shall be made up with clean dry metal, a 2 to 3 per cent reserve of which shall be kept for the purpose.

6. By means of a sprayer, Road Tar shall then be sprayed uniformly over the lightly rolled dry surface at the rate of 25 lbs. per 100 sq. ft. (or 6 tons per mile 10 ft. wide).

7. Coarse grit ¾ inch gauge (¼ inch to ¾ inch grade consisting of 70 per cent ⅜ inch to ¾ inch and 30 percent ¼ inch to ⅜ inch) shall then be spread uniformly, by spinning baskets at the rate of 3¼ cu ft. per 100 sq. ft. (1725 cu ft per mile 10 ft. wide).

8. The surface shall then again be rolled, first lightly over whole surface till all the bajri has gone into the interstices and shall then be thoroughly watered and finished off as ordinary water-bound-macadam. The surface shall be watched and rolling stopped when the binding materials are found to work upto about ½ inch to ¾ inch of the surface. Any depressions that may form shall be made up with ¾ inch gauge premix bajri.

9. Next day the surface shall be lightly rolled again and any unevenness removed.

10. The surface shall be allowed to dry for another day and traffic kept off.

11. The surface shall then be sprayed with tar at the rate of 18 lbs. per 100 Sq. ft. (4¼ tons per mile 10 ft. wide) and medium gauge (¼ inch to ⅜ inch) grit uniformly spread at 2¼ cu.ft. per 100 sq. ft. (1200 cu.ft. per mile 10 ft. wide) and rolled in.

12. The surface shall then be sealed with tar or bitumen at 14 lbs. per 100 sq ft. (3¼ tons per mile 10 ft. wide) and fine (⅛ inch to ¼ inch gauge) grit spread at 1½ cu.ft. per 100 sq. ft. (800 cu.ft. per mile 10 ft. wide) and the whole surface rolled in.

13. The road shall be kept closed to traffic for 4 to 5 days at least.

APPENDIX 'B'

SPECIFICATION FOR 'SEMI-GROUT' WITH 4 INCH. METALLING.

1. A $\frac{3}{4}$ in. to 1 in cushion of good clay earth shall be spread uniformly on the consolidated soling coat and thoroughly saturated and lightly raked

2. 2 in. thick stone metal of $1\frac{1}{2}$ in to 2 in gauge shall be closely and uniformly spread and hand-packed to proper camber over the earth cushion.

3 5 to 8 per cent free quarry screenings shall then be uniformly spread over the surface and washed down into the interstices with water.

4 The remaining 2 in thick of clean dry metal $1\frac{1}{2}$ in to 2 in. gauge shall then be *uniformly spread and particular care taken to closely hand*-pack it, so that the carpet is quite even and dressed to correct camber

5. The surface shall then be first rolled dry starting from the sides towards the centre and then consolidated with water as for ordinary 'water-bound-macadam'. The rolling shall be stopped when it is found that the surface is sufficiently consolidated, that roller wheels leave little impression on it and that the binding materials have worked upto about $\frac{1}{2}$ in to $\frac{3}{4}$ in. of the surface. Any depression that may appear shall be made up with the metal, a 5 per cent reserve of which shall be kept for the purpose from operation 2 and 4 above.

6 The surface shall then be allowed to dry out for a day or so and traffic kept off.

7. Road Tar shall then be uniformly sprayed by means of a sprayer over the dry surface at the rate of 25 lbs. per 100 sq. ft. (or 6 tons per mile 10 ft wide).

8. Coarse grit $\frac{3}{4}$ in. gauge ($\frac{1}{4}$ in to $\frac{3}{4}$ in. grade consisting of 70 per cent $\frac{3}{8}$ in to $\frac{3}{4}$ in. and 30 per cent $\frac{1}{4}$ in to $\frac{3}{8}$ in.) shall then be spread uniformly by spinning baskets at the rate of $3\frac{1}{4}$ cu. ft per 100 Sq. ft. (or 1725 cu. ft. per mile 10 ft. wide)

9. The surface shall then be rolled dry and the consolidation continued and completed till the bajri is firmly wedged in position and there is no movement of the surface under the roller.

10. Next day the surface shall be lightly rolled and any unevenness that may appear shall be removed with premixed grit.

11. When the surface has dried out, it shall be dusted and cleaned, tar sprayed at the rate of 18 lbs per 100 Sq ft. ($4\frac{1}{2}$ tons per mile 10 ft. wide) and medium gauge ($\frac{1}{4}$ in. to $\frac{3}{8}$ in) grit uniformly spread at $2\frac{1}{4}$ cu ft per 100 Sq. ft. (1200 cu. ft. per mile 10 ft wide) and rolled in

12 The surface shall then be sealed with *Road Tar or Bitumen* at 14 lbs per 100 Sq. ft. ($3\frac{1}{2}$ tons per mile 10 ft. wide) and fine grit ($\frac{1}{8}$ in. to $\frac{1}{4}$ in gauge) spread at $1\frac{1}{2}$ cu ft per 100 Sq ft. (800 cu. ft per mile 10 ft wide) and whole surface rolled and finished.

13. The road shall be kept closed to traffic for about 2 to 3 days at least.

Note—In operation 9, sprinkling of a little water over the surface after having lightly rolled in the bajri will be *found* beneficial.

APPENDIX 'C'.

BUILT UP SPRAY GROUT (DRY) SPECIFICATION WITH 4 IN. METALLING.

1. A $\frac{3}{4}$ in. to 1 in. cushion of good clay earth shall be spread uniformly on the consolidated soling coat.

2. 2 in. thick stone metal of $1\frac{1}{2}$ in. to 2 in. gauge shall be closely and uniformly spread and hand-packed to proper camber over the earth cushion. (This metal shall be from under the stacks, the top cleaner metal being kept for spreading on top).

3. 5 to 8 per cent. free quarry screenings shall then be uniformly spread over the surface.

4. The remaining 2 in. thickness of clean dry metal $1\frac{1}{2}$ in. to 2 in. gauge shall then be uniformly spread and particular care shall be taken to hand-pack it so that the carpet is quite even and dressed to correct camber.

5. The surface shall then be rolled dry starting from the sides towards the centre. Any depression that may appear shall be made up with the metal, a small (2 to 3 per cent.) reserve of which shall be kept for the purpose from operations 2 & 4 above. The dry rolling shall be continued till the metal gets fairly interlocked without crushing the metal.

6. Road Tar No. 2 shall then be uniformly sprayed by means of a sprayer over the dry surface at the rate of 30 lbs. per 100 Sq. Ft. (or 8 5 tons per mile 10 ft. wide).

7. Coarse grit—$\frac{3}{4}$ in. gauge ($\frac{1}{4}$ in. to $\frac{3}{4}$ in consisting of 70 per cent $\frac{1}{2}$ in. to $\frac{3}{4}$ in. and 30 per cent. $\frac{1}{4}$ in. to $\frac{3}{8}$ in., shall then be spread uniformly by spinning baskets at the rate of $4\frac{1}{2}$ cu ft. per 100 Sq. ft. (or 2400 Cu. ft. per mile 10 ft wide).

8. The surface shall then be rolled lightly with the S. R. Roller. Being fresh it will resume and form ridges under the roller wheels and therefore only a few turns shall be given just to lightly wedge in the grit and surface left to season.

9. Next day in summer and (after 5 or 6 hours in winter) the surface shall be thoroughly rolled till all the 1st coat grit is fairly wedged in position and there is no movement of the surface under the roller. Any unevenness that may appear in the final surface shall be removed with premixed grit.

10. When the surface has dried out, it shall be dusted and cleaned, tar sprayed at the rate of 18 lbs. per 100 Sq. ft. ($4\frac{1}{4}$ tons per mile 10 ft. wide) and medium gauge ($\frac{1}{4}$ in. to $\frac{3}{8}$ in.) grit uniformly spread at $2\frac{1}{2}$ Cu. ft. per 100 Sq. ft. (1200 cu. ft. per mile 10 ft. wide) and rolled in.

11. The surface shall then be sealed with tar or bitumen at 14 lbs. per 100 Sq. ft. ($3\frac{1}{4}$ tons per mile 10 ft. wide) and fine grit ($\frac{1}{8}$ in. to $\frac{1}{4}$ in. gauge) spread at $1\frac{1}{2}$ cu. ft. per 100 Sq. ft. (800 Cu. ft. per mile 10 ft. wide) and whole surface rolled and finished.

12. The road shall be kept closed to traffic for 4 to 5 days at least.

APPENDIX 'D'.

MODIFIED SPECIFICATION FOR 'BUILT UP SPRAY GROUT DRY SPECIFICATION' WITH 3 IN METALLING OVER BRICK OR STONE SOLING COAT

1. 1/2 in. to 3/4 in cushion of good clay earth shall be spread uniformly on the consolidated soling coat.

2. One layer ($1\frac{1}{2}$ in thick) of stone metal of $1\frac{1}{2}$ in gauge shall be closely and uniformly spread and hand-packed to proper camber over the earth cushion. Care to be taken to use metal from under the stacks and keep the cleaner metal for the top coat

3 5 to 8 per cent of free quarry screenings shall then be screened and uniformly spread over the surface.

4 The balance of $1\frac{1}{2}$ in. clean metal shall then be uniformly spread and particular care shall be taken to hand-pack it so that the carpet is quite even and dressed to correct camber.

5. The surface shall then be rolled dry starting from the sides towards the centre. Any depression that may appear shall be made up with the small (2 or 3 per cent) reserve of metal, which shall be kept for the purpose from operations 2 & 4 above The dry rolling shall be continued till the metal gets fairly interlocked, without crushing the metal It is imperative that when the dry rolling is completed, the surface should be absolutely uniform and in proper camber and grade

6. Road Tar No 2 shall then be uniformly spread by means of a *sprayer over the dry surface at the rate of 33 lbs per 100 Sq ft.* (or 7 75 tons per mile 10 ft wide)

7. Coarse grit 3/4 in gauge (1/4" to 3/4" consisting of 70 per cent 3/8 in. to 3/4 in and 30 per cent. 1/4 in. to 3/8 in) shall then be spread uniformly by spinning baskets at the rate of $5\frac{1}{2}$ cu. ft. per 100 Sq ft (or 2800 Cu. ft per mile 10' wide) and lightly rolled in.

8 Next day in summer — (the same day after 5 or 6 hours in winter) the surface shall then be thoroughly rolled dry till all the bajri is firmly wedged in position and there is no movement of the surface under the roller.

9 After a day the surface shall again be lightly rolled and any unevenness that may appear be removed with pre-mixed grit

10. The surface shall then be dusted and cleaned and tar spread at the rate of 21 lbs per 100 Sq ft. (5 tons per mile 10 ft wide) and medium gauge (1/4 in to 3/8 in.) grit uniformly spread at $2\frac{1}{2}$ cu ft per 100 Sq ft. (1300 cu. ft per mile 10 ft. wide) and thoroughly rolled in

11 Any small unevenness that might still be remaining in the surface should be taken out with pre-mixed bajri after the second coat

12 The surface shall then be sealed with tar or bitumen @ 14 lbs. per 100 Sq ft ($3\frac{1}{4}$ tons per mile 10 ft wide) and fine grit (1/8 in. to 1/4 in. gauge) spread at $1\frac{1}{2}$ cu. ft per 100 Sq ft (800 cu. ft. per mile 10 ft wide) *and whole surface rolled and finished.*

13. The road shall be closed to traffic for at least 4 to 5 days.

APPENDIX 'E'.

FINAL BUILT UP SPRAY GROUT (DRY) SPECIFICATION WITH 3 INCHES METALLING.

All operations are in accordance with the modified specification D, except that the quantities of binder and bajri in the various spray coats shall be as under.—

		Binder.	Grit. cu. ft.
1st Coat,	per 100 Sq. ft.	21 lbs.	5¼
	per Mile 10 ft. wide.	5.0 tons.	2800
II Coat,	per 100 Sq. ft.	30 lbs.	2⅝
	per Mile 10 ft. wide.	7.0 tons.	1400
III Coat,	per 100 Sq. ft.	17 lbs.	1⅜
	per Mile 10 ft. wide.	4.0 tons.	700
Total	per 100 Sq. ft.	68 lbs.	9¼
	per Mile 10 ft. wide.	16 tons.	4900

APPENDIX 'F'.

Statement showing quantities of Binder and Grit used in the various specifications adopted on Road work in Mianwali Construction Division (Roads).

Description.	SPECIFICATION							
	Semi-grout with 1" metal.		Built-up spray-grout (dry) with 1" metal		Modified B U.G (dry) with 3" metal		Final B U.G (dry) with 3" metal.	
	Binder	Grit.	Binder	Grit	Binder.	Grit.	Binder.	Grit
1st Coat 100 sq ft per mile 10' wide	25 lbs 6 tons	3¼ Cft. 1725 Cft	36 lbs 8 5 tons	4½ Cft. 2100 Cft	33 lbs. 7·75 tons	5¼ Cft 2800 Cft	21 lbs. 5·0 tons.	5¼ Cft 2800 Cft
IInd Coat 100 sq. ft. per mile 10' wide	18 lbs. 4½ tons.	2¼ Cft. 1200 Cft	18 lbs. 4½ tons.	2¼ Cft. 1200 Cft	21 lbs 5 0 tons	2½ Cft. 1300 Cft.	30 lbs 7 0 tons.	2⅝ Cft. 1400 Cft
IIIrd Coat 100 sq ft. per mile 10' wide	14 lbs 3¼ tons	1½ Cft. 800 Cft	14 lbs. 3¼ tons.	1½ Cft 800 Cft.	14 lbs 3¼ tons.	1½ Cft 800 Cft	17 lbs 4 0 tons	1¼ Cft 700 Cft
Total 100 sq. ft per mile 10' wide.	57 lbs 13½ tons.	7 Cft 3725 Cft.	68 lbs 16 0 tons.	8¼ Cft. 4400 Cft.	68 lbs 16 0 tons	9¼ Cft 4900 Cft	68 lbs 16 tons	9¼ Cft 4900 Cft

APPENDIX 'H'.

Comparative statement showing average cost per mile done with various specifications (including soling coat but excluding cost of formation).

Particulars.	Cost of Wearing coat crust and surfacing per mile 10 ft width. Rs	Add 22½ per cent average premium paid over peace-time rates due to War conditions. Rs.	Total cost per mile 10 ft. width Rs.	Average rate per 100 Sq ft of finished surface. Rs.	Remarks.
(1)	(2)	(3)	(4)	(5)	(6)
1. Built-up-Spray Grout-dry 4 in.	6,674	908	7,582	14/6/-	For total cost including soling coat but excluding formation, please add cost of soling given against items 5, 6, 7 & 8.
2. Modified and final B. U. G (dry) 3 in.	5,993	754	6,747	12/13/-	
3. Semi-grout 4 in.	6,226	900	7,126	13/8/-	
4. Semi-grout 3 in.	5,462	728	6,190	11/12/-	
5. Stone soling 3 in. thick	3,233	727	3,960	7/8/-	
6. Stone soling 6 in. thick	4,722	1,062	5,784	10/15/-	
7. Brick on edge soling 4½ in. thick	4,100	923	5,020	9/8/-	
8. Flat Brick soling 3 in. thick	2,761	621	3,380	6/6/-	

APPENDIX 'H' (a).

Details of cost of Wearing-Coat-Crust complete with Surfacing per mile 10 ft. wide for various specifications.

I. Built-up-spray Grout (dry) with 4 inches metalling.

	Quantity.	Rate. Rs. a. p.	Per unit	Amount. Rs
(i) Metal collection.	17600 cu.ft	13-10-0.	100 cu ft	2398
(ii) Consolidation	17600 „	3-12-0.	„	660
(iii) Road Tar No 2.	16 tons.	165- 0-0.	ton	2640
(iv) Grit	4400 cu.ft	16- 8-0.	100 cu ft	726
(v) Labour for surface treatment		250-0-0.	mile.	250
			Total :—	6674

II. Modified and Final Built-up-spray Grout (dry) with 3 inches metalling.

	Quantity.	Rate.	Per unit	Amount.
(i) Metal collection.	13200 cu ft	13-10-0	100 cu ft	1799
(ii) Consolidation	13200 „	3-12-0	„	495
(iii) Road Tar No 2	16 tons	165- 0-0.	ton.	2640
(iv) Grit.	4900 cu ft	16- 8-0	100 cu ft	809
(v) Labour for surface treatment.		250- 0-0.	mile.	250
			Total —	5993

III. Semi-grout with 4 inches metalling

	Quantity.	Rate.	Per unit	Amount.
(i) Metal collection.	17600 cu ft	13-10-0	100 cu ft	2398
(ii) Consolidation	17600 „	3-12-0	„	660
(iii) Road Tar No. 2	13½ tons	165- 0-0.	ton	2228
(iv) Grit.	3725 cu ft	16- 8-0	100 cu ft	615
(v) Labour for surface treatment		250- 0-0	mile.	250
(vi) Watering.		75- 0-0.	mile.	75
			Total :—	6226

IV. Semi-grout with 3 inches metalling.

	Quantity.	Rate.	Per unit	Amount.
(i) Metal collection.	13200 cu ft.	13-10-0	100 cu.ft	1799
(ii) Consolidation.	13200 „	3-12-0.	„	495
(iii) Road Tar No. 2.	13½ tons	165- 0-0	ton	2228
(iv) Grit.	3725 cu. ft.	16- 8-0	100 cu. ft	615
(v) Labour charges		250- 0-0.	mile	250
(vi) Watering.		75- 0-0	mile	75
			Total :—	5462

APPENDIX 'H' (b).

Details of cost of Stone Soling and Brick Soling per mile with various Thicknesses—Width-11 feet.

I. Stone Soling 3 inches thick.

	Quantity.	Rate. Rs	a.	p.	Per unit.	Amount. Rs.
i Soling stone 3 inches gauge ..	14520 cu. ft.	19	0	0	100 cu. ft.	2759
ii. Consolidation	14520 ,,	2	12	0	,,	399
iii. Watering ..		75	0	0	mile	75
Add average premium @ 22½ per cent						727
					Total	3960

II Stone Soling 6 inches thick.

	Quantity.	Rate. Rs	a.	p.	Per unit.	Amount. Rs.
i Soling stones .	29040 cu ft.	13	4	0	100 cu ft.	3848
ii. Consolidation .	29040 ,,	2	12	0	,,	799
iii. Watering .		75	0	0	mile	75
						4722
Add average premium @ 22½ per cent						1002
					Total	5784
					Say	5780

III. Brick Soling 4½ inches thick.

	Quantity.	Rate. Rs	a.	p.	Per unit.	Amount. Rs.
i Collection of bricks	21780 cu. ft.	16	0	0	100 cu. ft.	3480
ii. Consolidation .	21780 ,,	2	8	0	,,	545
iii. Watering ..		75	0	0	mile	75
Add average premium @ 22½ per cent						923
					Total	5023
					Say	5020

IV. Brick Soling 3 inches thick.

	Quantity.	Rate. Rs	a.	p.	Per unit.	Amount. Rs.
i Collection of bricks	14520 cu. ft.	16	0	0	100 cu ft.	2323
ii. Consolidation ..	14520 ,,	2	8	0	,,	363
iii. Watering .		75	0	0	mile	75
Add average premium @ 22½ per cent						621
					Total	3382
					Say	3380

Monday, Oct. 4th, 1943.

Mr. J. Vesugar (Chairman) called upon Mr. Abdul Aziz to introduce his paper. The above paper was taken as read. Mr. Abdul Aziz introducing the paper said :—

My paper deals with the speedy and economical specifications adopted for the construction of certain Strategic Roads in the North west of the Punjab. The areas in which the roads have been built are difficult, dry, mostly barren, and cover sandy, plain, hilly, semi-hilly, and badly broken craggy land. Rainfall is low—about 6 ins. to 10 ins. There are no canals.

Acute scarcity of water even for drinking purposes and difficulty of transport of materials over the old, rough, steep tracks were the difficulties to be tackled.

In the Punjab the general practice is to use 6 ins. stone or 4½ ins. brick on edge for the soling or base coat. On these roads 3 ins. flat brick and 3 ins. to 4 ins. stone soling has also been used in certain miles as detailed on pages 163 and 165, according to the availability of materials and nature of sub-grade.

Use of thin soling coat is not an established practice and the miles done as such on these roads may be considered as an experiment on a large scale. Bullock cart traffic is light in this area and so far the miles with thin soling coat have stood up well to motor traffic, which has been as much as 1,200 tons a day over certain miles.

Construction of water-bound macadam *according to old practice* and sealing with tar or bitumen *after sometime* practically out of date in the Punjab.

The specifications followed for the building of the wearing coat crust fall under two categories : (a) wet and (b) dry.

(a) Where sufficient water could be had expeditiously and at reasonable expense, saving of time being the guiding factor, the semi-grout specification as detailed in Appendix B was followed. In this specification the wearing coat is partially (about 80 to 90 per cent.) consolidated as per ordinary water-bound and rolling is stopped when the metal is fully interlocked and the filler or blinding from the bottom has worked up to within 1/2 in. to 3/4 in. of the surface.

Three coats of Road Tar No. 2 were then applied (mostly with the Harris Trolley Sprayer) at the rate of a total 57 lbs. of tar and blinding with 7 cu. ft. of 1/8 in. 3/4 in. gauge grit and surface finished as per operations given in the specifications. 170 miles have been done to this specifieation in my Division alone.

(b) In miles where sufficient water could not be had for the wearing coat, the all-dry specification, called the built-up-spray-grout (dry), was adopted. Detail of operations is given in Appendices C to E. The wearing coat was consolidated dry and then spray-grouted and finished with three coats of tar at the rate of a total of 68 lbs. of binder and 8¼ cu. ft. of 1/8 in. to 3/4 in. grade grit per 100 sq. ft. This specification is a

fairly close proximation to tar concrete at a very much reduced cost 107 miles have been constructed to this specification.

The actual average cost of the two specifications including 22½ per cent. premium imposed by War conditions has been only Rs. 6,196/- to Rs. 7,582/- per mile 10 ft. wide or Rs. 11/12/- to Rs. 14/6/- per 100 sq. ft. Please see Appendix H, page 181. The dry specification cost about Rs. 500/- more than the semi-grout. The economical and speedy semi-grout or the wet specification has already been very successfully followed in the construction of other Provincial Roads too; but the built-up-grout dry specification as detailed in the Paper has been tried on a large scale only on the Strategic Roads. The specification is standing up very well under traffic and the results have been very encouraging. Behaviour of these specifications has been discussed in the Paper at page 172. I trust the lead given by the Punjab in trying out and evolving these economical and at the same time durable specifications will be of use to other Provinces.

Mr. N. T. Gnanaprakasam, (Madras) :—

With regard to soling coat, it would be of interest to know if gravel (moorum) was used as a soling coat. Gravel has been used successfully as a soling coat and it would have been particularly suitable for expeditious work. It is also less expensive. I would like to be informed if it was deliberately discarded and if so for what reasons.

With regard to the modified Built-up Spray Grout or Semi Grout described on page 167, it is stated that a little quantity of water is added after the first coat of tar was sprayed and consolidation completed. And in the foot note on page 176, it is also stated that sprinkling of a little water over the surface after having lightly rolled in the chips will be found beneficial." Generally speaking, better penetration of tar can be expected only when it is still hot and the presence of water and moisture is not conducive to better bleeding of the bitumen. It, therefore, appears a little strange that the addition of water at that stage should improve the surface. I shall be thankful if the learned author throws some light on the subject.

It is seen from the statement given on page 169 that the specification which was most extensively adopted is the semi-grout specification. Comparing the specification described in Appendix "B" with the specification given in paper H-39† by Rao Bahadur A. L. Rao, the main difference appears to be that the spraying in the present specification is done in three different operations, whereas in the 1939 specification, it is done in one operation. In both the specifications, approximately the same quantities of bitumen and jelly are used. The 1939 specification has one advantage in its favour that it is quicker and would therefore be suitable for expeditious work as in the present case. No doubt the 1939 specification was recommended mostly for existing water-bound macadam roads but there appears to be no reason why it should not be adopted for new constructions also. I would like to know if that specification was tried and if so with what results.

† Paper No. H-39—An economical substitute for water bound macadam, by A. Lakshminarayana Rao —Sixth Proceedings.

Rai Sahib Fateh Chand (U. P.)

Specifications.

Use of clay.—Clay in a thin layer is certainly useful in newly constructed roads but the quantity in my opinion should not be more than the minimum required to fill up the voids. The quantity used in this case appears to me to be too much for 1½ inches or 2 inches thick layer of metal spread over it. My experience is that if the whole of the clay is not used up in filling voids, the balance left between the wearing coat and the soling coat forms a soft base for the wearing coat and results in undulating surface particularly under the action of water from the sides as the berms are not always maintained in level with the surface of the roads.

Use of screenings.—I have not tried this method and I do not know what advantage would result by giving screenings in between two layers of 1½ or 2 inches thickness of the wearing coat. To me it appears to be superfluous and disadvantageous inasmuch as it separates the wearing coat into 2 thin layers. I would like to know if any portion or portions were made without the use of screenings in between the two layers and if so with what results.

Grit, Gauge of screenings.—Instead of using from 1/4 inch to 3/4 inch gauge in one lot, it might be found to be better to separate the grit into 1/2 in. to 3/4 in. gauge and 3/4 in. to 1/2 in. gauge respectively. This method was demonstrated by a representative of the Burmah Shell on the Nehtaur Dhampur road in Bijnor District and was found to give much better results than 1/4 in. to 3/4 in. grit spread in one lot.

The author complains of scarcity of water. Did he try the methods of grouted and semi-grouted roads described in Mr. S. N. Chakrabarty's paper which do not require the use of any water ? Also the road could be opened to traffic earlier if surface painting had been done instead of grouting.

Formation and sub-grade.—I agree with the author that a low formation has several advantages and should in my opinion be accepted as a rule even for ordinary roads in the District. One of the greatest advantage of a low level formation is that the road metal has a longer life due to a comparatively more stable sub-grade, and that it is very much easier and less costly to maintain the berms, which are a constant source of trouble in the case of high formation roads. I have noticed that on the Bijnor-Meerut road, where the formation level is about 3 feet above the surrounding ground level, the berms get always broken up and become lower than the level of the metalled portion particularly where the soil is soft, while on Bijnor-Gunj Road on which the formation level is only 9 inches above the surrounding level, the berms are always maintained in good condition at half the expense. When I was sent to the Punjab in 1928 to study the road grading system there, under the guidance of Mr. S. G. Stubbs, I. S. E., I came across a note by Mr. Mitchell emphasising the point that the soil at a low level is comparatively more stable than that at a high level. During the past fourteen years, this has been fully proved by experience on the maintenance of

both the Katcha and Pucca roads . The chief reason stated by Mr. Mitchell was that the moisture near the surface helps the low-level roads a great deal and grass grows more easily on them than on high-level ones.

Soling Coat.—In the Bijnor District, I have successfully used three inches brick or 1½ in brick ballast (before consolidation) for average traffic roads According to my experience, the surface of metal consolidated on sandy portions is not as lasting as in the case of roads on firm soil The portions of the Chandepur-Seohara and Nehtaur-Sherkot roads laid on sandy soil are a constant source of trouble The reason is clear. The sides of the sandy sub-soil not being confined, the sand slips out under the vibrations and weight of the traffic, and there are occasional patches The trouble of consolidating the soling coat on heavy sand by means of a ten ton roller is always there. Two sets of rollers are not available in all cases, particularly so far as the district engineers of the *District Boards are concerned. They have to work with one roller only.* The remedy that I tried successfully was to put 2 inches clay over the sandy soil which not only made it easier to consolidate the soling coat but also gave the metalled surface greater permanent stability. Laying bricks completely together instead of broken brick ballast after sprinkling water over the sandy surface was also found helpful. In my opinion the gradient of the road should not be increased disproportionately to cross the sand dunes A little clay put over the berms helps such portions a great deal. Sand coming over the water-bound macadam surface is helpful as it acts as blinding. Extra quantities can be removed by the permanent gangs.

Mr. H. A. Harris (Punjab). By Correspondence:—

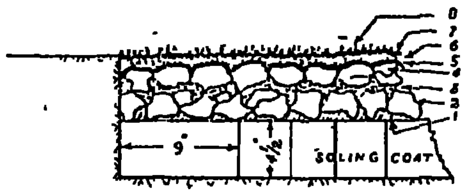
1. I would like to congratulate Mr. Abdul Aziz for his very interesting paper in which he has outlined in an apt and concise manner various specifications used for the construction of strategic roads in his Division and in fact for all new road construction in this circle.

2. As stated by him, these specifications constitute almost revolutionary change in the mode of road construction and is a complete switch over from the orthodox form of ordinary water-bound macadam with two coats of tar. One of the main advantages in spray penetration or semi-grout is that it is a very elastic specification and provides a very rapid form of construction which can easily be modified to meet nearly every condition which may confront a Road Engineer during construction. It also enables the use of soft aggregate to the best advantage

3. Built-up-Spray-Penetration is really an easy way of obtaining in situ an aggregate coated with binder or premix or tar macadam. It was first adopted by me in 1931-32 on the Kalka-Simla Road where I had been laying premix carpets, but on account of the narrow width of this hill road and difficulties experienced with heating and curing the aggregate coated with binder, it was found necessary to find a more easier mode of construction. Later in 1934-35 in the Lyallpur Division, a number of miles on the Lyallpur Chiniot Road were constructed to the specification given below, but as my Superintending Engineer at the time was not in favour of this mode of construction, majority of miles were

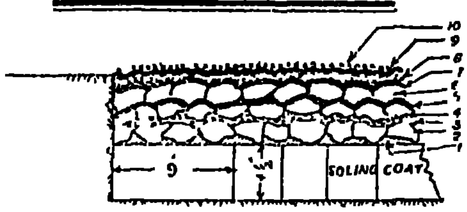
BUILT-UP - SPRAY GROUT

SPECIFICATION No. 1



1. 3/4 IN TO 1 IN LAYER OF EARTH WELL SPRINKED WITH WATER
2. 2 IN COAT OF METAL CLOSELY HAND PACKED & SATURATED WITH WATER
3. 5% QUARRY SCREENING WITH RACKING & SCREENING FROM UNDERNEATH THE METAL STACK & SATURATED WITH WATER
4. 2 IN COAT OF METAL CLOSELY HAND PACKED
5. SPRAY COAT OF No 2 TAR OVER LIGHTLY ROLLED SURFACE AT RATE OF TWO GALLONS PER % SFt i.e 7 TONS PER MILE 12 Ft ROAD OR 24½ LBS % SFt
6. COARSE LOCAL HARD SAND STONE OR PATHANKOT BAJRI ½ IN TO ¾ IN GAUGE, SPREAD UNIFORMLY AT 3½ C Ft PER % SFt
7. SPRAY COAT OF TAR OR BITUMEN AT 6 TONS PER MILE 12 Ft ROAD OR 17 GALLONS PER % S Ft OR 20 LBS % SFt
8. PATHANKOT BAJRI ¼ IN TO 3/8 IN & 1/8 IN TO ¼ IN SPREAD UNIFORMLY IN TWO SEPARATE OPERATIONS AT 2 C Ft PER % S Ft

SPECIFICATION No. 2



1. 3/4 IN LAYER OF EARTH WELL SPRINKED WITH WATER
2. 2 IN COAT OR 10560 C Ft OF METAL PER MILE 12 Ft WELL SATURED WITH WATER
3. 5% QUARRY SCREENING UNIFORMLY SPREAD & WELL SATURATED WITH WATER
4. 1¼ IN COAT OR 6600 C Ft OF METAL PER MILE 12 Ft CLOSELY HAND PACKED & LIGHTLY ROLLED
5. SPRAY COAT OF TAR @ 5 TONS PER MILE 12 Ft OR 14 GALLONS PER % S Ft OR 17 LBS % S Ft
6. 1¼ IN COAT OR 6600 C Ft OF METAL PER MILE 12 Ft CLOSELY HAND PACKED & ROLLED
7. SPRAY COAT OF TAR No 2 AT 6 TONS PER MILE 12 Ft OR 17 GALLONS PER % S Ft OR 20 LBS % S Ft
8. COARSE LOCAL HARD SAND-STONE OR PATHANKOT BAJRI ½ IN TO ¾ IN GAUGE SPREAD UNIFORMLY @ 3½ C Ft PER % S Ft
9. SPRAY COAT OF TAR OR BITUMEN @ 5 TONS PER MILE 12 Ft WIDE OR 14 GALLONS PER % S Ft OR 17 LBS % S Ft
10. PATHANKOT BAJRI ¼ IN TO 3/8 IN & 1/8 IN TO ¼ IN SPREAD UNIFORMLY IN TWO SEPARATE OPERATIONS AT 2 C Ft PER % S Ft

NOTE - FOR RENEWALS OF AN OLD METALLED ROAD SCARIFY THE SURFACE, RAKE & DRESS THE SUB-GRADE TO CAMBER, THEN LAY METAL AS ABOVE ON SATURATED SURFACE. NO ADDITION OF EARTH IS NECESSARY.

constructed to the semi-grout water-bound specification (more correctly called spray-grout or spray penetration). This specification was, however, almost entirely given up in favour of built-up-spray penetration for the Lyallpur Jhang Road, major portion of which was constructed under the supervision of Mr. Abdul Aziz, firstly as Student Engineer under training and later as S D O, as it was found that with soft sand-stone metal without the use of blinding on top as is customary with water-bound macadam, the metal tended to crush necessitating either using more tar, or brushing out the crushed metal before applying the first spray coat. At that time I was limited to use only 12 tons of tar per mile for a 12 ft. width, as this was the quantity sanctioned for ordinary water-bound macadam with two coats of tar. However, by reducing the labour cost for surface painting, as no cleaning of the road with brushes had to be done with this specification, I was able to save sufficient money for the provision of two more tons of tar per mile, making 14 tons in all per mile 12 ft. width or 49 lbs per 100 sq. ft.

4. Both these roads at the present time are in excellent condition and all the miles have maintained their camber and the riding surface is one of the best in the Province which, I think, speaks for itself for this specification The soling coat was brick on edge laid diagonally.

5 In the early stages of this type of construction, the heavier spray-coat was provided for the initial spray, but it was found that specially if a road has light traffic, it is advisable to reduce the quantity in the initial coat and make each coat more or less the same, tending, if anything, to the heavier coat being given on top.

6. For runways and dispersal tracks of airfields constructed in this circle, the specification adopted is 4 spray coats (Mexphalte 80-100 penetration) each of 17 lbs (for detailed specifications see pages 185 h to 1) making 68 lbs in all. This has since been modified and the first 3 spray coats have been reduced to 14 lbs each and the final coat 17.5 lbs. per 100 sq. ft. making approximately 60 lbs. per 100 sq. ft. for the completed surface.

7. Where water was available, it has been used, but the major portion of the dispersal tracks and majority of hard standings have been constructed dry

8. Use of water for spray-penetration-consolidation has been very much criticised, but I am convinced from my observations and results obtained that the use of water is not injurious and the results obtained are very much better where water is used. Mr. Abdul Aziz has given interesting figures of water required and it will be seen that the quantity is not much The quantity of water should be kept down to an absolute minimum and only sufficient water given to make the hoggin or cushion below plastic, so that voids left after mechanical locking are filled from underneath and a good bedding is provided to the under side of the metal.

9 Use of water on brick ballast before spraying has proved most valuable as it is found that the absorption into the brick ballast is

materially reduced if this is done. It has also been found that instead of giving a heavy initial coat on brick ballast, or friable, or open texture sand-stone, it is definitely beneficial to give the same quantity in two thin consecutive coats; the first spray-coat after it has set or coagulated into the pores of the metal tends to reduce the absorption of the subsequent coats by the aggregate.

10. An interesting experiment has very recently been tried with success on the Lyallpur Toba Tek Singh Road with built-up-spray penetration consolidation without the use of any bajri. Owing to the restriction in obtaining railway wagons for roads which are not of military importance, no bajri could be obtained for this road. For the entire length, metal had been collected prior to the war and a brick soling laid and as the soling was showing marked signs of rutting, it was decided to try and save it from further deterioration by providing a wearing coat.

11. At first no steam roller was available and it was therefore decided to consolidate these miles with 1½ ton bullock roller hauled by manual labour. Two miles were actually completed in this manner after which two rollers were obtained and in all upto date nine miles have been consolidated. The specification adopted was practically the same as specification No. 2 except that no bajri was used and instead all the metal was screened and graded out into three grades *i. e.* Grade I, 1½ in. 2 in. gauge, Grade II, 1 in.—1½ in. gauge and Grade III 1 in. and below with 5 per cent. screenings free of earth. The wearing coat laid was 3 ins. The operations for this work were briefly as detailed below:—

(1) ¾ in. to 1 in. layer of earth on soling sprinkled with water and raked ;

(2) The equivalent of 1½ ins. coat of metal, 1½ ins. to 2 ins gauge, closely hand packed and lightly rolled ;

(3) Spray tar at 17 lbs. per 100 sq. ft ;

(4) Spread the equivalent of ¾ in. to 1 in. of metal, 1 in. to 1½ in. gauge with spinning baskets ;

(5) Roll again lightly and water sparingly ;

(6) Spray with 20 lbs. of tar per 100 sq. ft. ;

(7) Spread the remaining 1 in. gauge metal and all screenings free of dust ;

(8) Roll and water fairly liberally, then blind with sand or silt approximately 400 cu. ft. per mile.

12. With the light roller it was found that very good results were obtained by using 1,000 ft. of 1/8 in. to 3/8 in. bajri per mile instead of sand. For this purpose a portable granulator was used, but it went out of order and in the remaining 7 miles which were consolidated with steam roller, no extra bajri was used, but instead excessive rolling was done to pulverise the stone and so fill the voids.

13. These miles have been under traffic for 6 months and are in excellent condition and it is difficult to distinguish their surface

from those constructed to specification in which bajri is used. Further work on this road, however, has been stopped in order to conserve binder for more important roads

Specification for four-Spray-Coat Work.

Consolidations of wearing coat and surfacing.

After the cambre on the soling has been checked, two bunds of clay puddle 9 inches wide and 6 inches deep shall be made along the outer edges of the metalling and the inside edges made vertical by placing a plank at the time of moulding these bunds The stone metal shall then be spread uniformly to a depth of about 2 inches over the soling (without removing the earth from the soling) and the fines available in the stacks of metal or the screenings supplied separately shall then be spread uniformly over it. Immediately the screenings and fines have been spread, a coat of metal equivalent to 1 inch shall then be spread over the surface. All metal shall be spread by spinning baskets so as to ensure a uniform intensity of spreading over the entire width of the runway surface. This spreading with a spinning basket is absolutely essential as it not only ensures uniform settlement but also greatly helps in securing effective mechanical locking and a quicker consolidation of metal with the minimum amount of crushing of the stone.

After 3 inches of metal is spread in the above manner, the surface shall be sparingly watered to wash in the chips into the interstices. When a sufficient length of the full width of the runway has been covered with metal, the surface shall be lightly rolled.

1st Spray. It shall be carefully seen that the surface has previously been washed or dusted clean of mud and dust. Then by means of a trolley sprayer or a light tar sprayer or a sprayer attachment to a tandom roller, spray over this lightly rolled surface, which must be quite dry, with 17 lbs. of tar or bitumen per 100 sq ft.

The remaining metal, which is equivalent to 1 inch, shall then be spread again with spinning baskets, particular care being taken that the whole surface is uniformly covered.

Again roll the whole surface until all the metal has worked into the carpet Then thoroughly water and finish off as for ordinary water bound macadam. Watch the surface and stop rolling just when the blinding material is observed to have worked up to within ¾ in to 1 in. of the surface This will be observed first on either side of the metalled width Make up any depressions which may form with metal and again check at this stage to see that the runway is to the correct camber.

2nd Spray Coat Next day roll lightly again and remove any unevenness of the surface Then spray a second coat of 17 lbs. of tar or bitumen per 100 sq. ft Spraying should be applied uniformly and diagonally over the full metalled width. Over this spread grade I bajri ¼ in to ⅝ in, at 2½ cu ft per 100 sq. ft. evenly and roll lightly till all the bajri has gone into the interstices

3rd Spray Coat After a good length of the runway has been given a second spray coat, a third spray coat is then to be given using 17 lbs.

of tar or bitumen and $2\frac{1}{2}$ cu. ft of grade II bajri ($\frac{1}{4}$in. to $\frac{3}{8}$ in.) per 100 sq ft. Roll again and check the camber making up any depressions which may form.

Final Spray Coat. To finish off the surface, a fourth and final spray coat is to be applied immediately after or the next day at 17 lbs. of tar or bitumen per 100 sq. ft. and over this spread 2 cu. ft. of grade III bajri ($\frac{1}{8}$ in. to $\frac{1}{16}$ in.) per 100 sq. ft. care being taken to see that this bajri, as in previous cases, has been uniformally spread over the surface with spinning baskets, until all the interstices are filled. Roll until this layer of bajri has worked into surface and a smooth, compact granular mosaic surface is obtained.

Note As an alternative specification, three spray coats may be done by omitting the spray coat between the two layers of metal and by increasing the quantity of tar or bitumen in the 3rd spray coat, which now becomes the second spray coat. Water for consolidation purposes in this specification shall be applied after the first spray coat has been given and grade I bajri spread. Other stages are exactly the same as in the above specification.

Collection of grit.

Grit shall consist of good hard tough and clear water worn bajri obtained from nallah beds, screened and stacked in boxes of 25 cu ft. each. The source from which the grit shall be obtained must be got approved by the Executive Engineer. If collection has been carried out in wet weather or earth or clay is found adhering to grit, the contractor shall rescreen it before acceptance at his own expense The grit shall be free from dirt, clay, leaves or organic matter and soft or decayed stone, and shall be of the square mesh specified. Screens used for cleaning and grading the grit shall be provided by the contractor. If screens are arranged for the use of the contractor, he shall have to pay the cost of the same.

Dispersal Tracks

For dispersal tracks specification is the same as outlined above with the exception that soling coat has been reduced to 4 inches and wearing coat to 3 inches instead of 6 inches and 4 inches given above. Where bricks are available, certain approach roads will be constructed with soling of brick on edge instead of 4 inches stone soling.

Mr. Abdul Aziz (Punjab)

I am grateful to Mr. Harris for his comments and for adding valuable and interesting information about the specifications used in his Circle for the construction of runways with bitumen and the experiment done on the Toba Tek Singh-Kamalia Road. I have had the chance of seeing the runways under construction and the finished surface is excellent. As mentioned at page 172 of the Paper, the Tandem Roller with bitumen boilers carried on tenders devised by Mr. Harris admirably suited for built-up-spray grout work with bitumen.

Referring to comments by Mr. N. T. Gnanaprakasam, Madras, I have to say that gravel (moorum) was not used as a soling coat; it is

not also clear to me as to how moorum or gravel which is ordinarily of small gauge can serve as a satisfactory soling coat under 2 in gauge metal coat over earth sub-grade. It is also not available in the area in which the works have been done The question of discarding or adopting such soling coat therefore never arose.

In the semi-grout or wet specifications, Appendix B, it is laid down that after spraying first coat, spreading bajri and rolling it in, little water be added and consolidation be completed Addition of water is to be when the binder has penetrated to the maximum extent. As regards the advisability of adding water, I quote here the comments of Mr Harris:—

> "Use of water for spray penetration consolidation has been very much criticised. But I am convinced from my observations and results obtained that the use of water is not injurious and the results obtained are very much better where water is used "

Some miles have been done without adding water and some with the addition of water The specification with water is found to better, hence the mention of this general practice on page 167.

The built-up-spray-grout specification was originally given extensive trials in the years 1934-35 and the semi-grout specification was also adopted extensively on Jhang-Lyallpur Road in 1937-38 The same quantity of binder and grit was used in two as well as in three operations The three coat work gave much better surface than the two coat work with practically no extra cost The three coat work builds up the surface much better than the two coat and consequently the question of trying one coat work did not arise. In the three coat work the spray operations make the surface a pre-mix carpet If only one operation is done, all the binder will remain in the metal and if the traffic is not heavy, it will have no chance to work up.

I thank all the Members who have made comments on the Paper and will be very glad to supply any further information that is required by any Member in connection with the specifications

PAPER No J-1943

PROPOSALS FOR AN ALL-INDIA SURVEY OF BULLOCK CARTS BY MEANS OF RANDOM SAMPLING.

BY

J. VESUGAR, B. Sc , A. M. I C. E., I. S. E.
Consulting Engineer to the Government of India, Roads.

1. Every ton of produce moved in India, whatever its ultimate destination or method of transport, must travel by cart for the first stage of its journey The bullock cart has continued unchanged for five thousand years and there is little reason to suppose that it will be supplanted in our time by any other method as a primary means of transport. So long as the road transport requirements were such that they could be met by this type of conveyance, it was a comparatively easy matter to maintain roads in suitable manner.

2. The bullock cart, however, specially the iron tyred variety, is a serious destroyer of the road. Ordinary water bound macadam which formerly wore into tolerably smooth ruts under slow traffic, breaks up rapidly under the combined grinding action of the slow iron tyre and the suction and scattering of the fines caused by the fast rubber tyred wheel. Modern tar or asphalt painted surfaces seem to be able to withstand the iron tyred wheel even less, the water proof skin being quickly broken by the high concentration of load

3. Road Engineers have been much disturbed by the destructive tendency of the narrow iron tyre and there have been frequent discussions in various engineering societies in India on this subject Whilst no engineer denies the destructive action of the iron tyred bullock cart, opinion is divided as to the extent to which this is a problem and even more divided as to the means necessary for its solution. There are all shades of opinion from the heroic remedy of placing all of India's seven million carts on pneumatic tyres, at a cost of something like a 100 crores, or the even more heroic suggestion of converting India's 70,000 miles of metalled road to concrete at a cost of 150 crores, to the other extreme which maintains that there is no bullock cart problem.

4. Whilst the special type of cart which takes 35 and sometimes as much as 50 maunds may give spectacular proof of the damage done and the figure for the load concentration per square inch may be startling, casual observation in all parts of the country gives the impression that the general capacity of a cart averages less than 15 maunds. Similarly, in many parts, one may go miles and meet hundreds of carts without seeing a steel tyre. It is arguable that a steel tyred cart carrying only 10-15 maunds, cannot cause very much damage, even if the tyre is narrow to begin with and gets rounded with use, but the wooden tyred cart can hardly be accused of being a serious road destroyer.

5. The only type of road that will stand up to the heavily loaded steel tyre is concrete, the really sensible wheel for any road transport purpose is the pneumatic tyred one. What should be one's

objective then, the concrete road or the pneumatic tyre? Would the answer vary for different areas? It would depend upon the numbers of heavy carts, the work they are engaged on, and the milage of road they use.

6. Though the total number of bullock carts in each province, perhaps in each district, is known, little information about these is available: for example, the type of carts, the loads they carry, the number of days worked or the milages travelled. Existing information such as figures of population, number and size of villages, area of agricultural land, agricultural produce, land revenue and its incidence, road milages, when examined against the "cart population" of each province, show some interesting regularities and some curious anomalies.

7. Such statistical information as has been published or is readily available, has been collected in the annexed table. It is interesting to observe from this table the inter-relation between the size of villages, density of population, density of cultivation, and to compare these with the cart population of the province. Other figures bearing on the problem have been collected in the same table. In order to judge their inter-relation and to compare the provinces, averages have been deduced from the information collected.

8. One may expect that the number of carts would depend upon the agricultural produce and the population in an area, and this assumption is largely borne out in actual practice. This is noticed if the provinces are placed in the order of the number of carts per thousand tons of produce, or per thousand of population, or per square mile of agricultural area.

	Carts per 1000 persons.			Carts per 1000 tons produce.			Carts per square mile
1.	C.P.	69.3	1.	C.P.	296	1.	C.P.	22.3
2.	Bombay	38.7	2.	Bombay	183	2.	Madras	19.2
3.	Bihar	37.6	3.	Madras	137	3.	U.P.	18.0
4.	Madras	25.1	4.	Orissa	120	4.	Bengal	17.6
5.	Sind	22.5	5.	Sind	95	5.	Orissa	14.2
6.	Orissa	20.4	6.	Bihar	94	6.	Bihar	14.1
7.	U.P.	20.0	7.	U.P.	82	7.	Bombay	11.4
8.	Punjab	11.6	8.	Bengal	72	8.	Sind	6.3
9.	Bengal	11.1	9.	Punjab	53	9.	Punjab	6.0
10.	Assam	7.1	10.	Assam	35	10.	Assam	5.8
11.	N.W.F.P.	1.8	11.	N.W.F.P.	8	11.	N.W.F.P.	1.3

9. It will be seen that C.P. is consistently first, whilst the Punjab, Assam and N.W.F.P. remain 8th or 9th, 10th and 11th respectively in each case. This is peculiar when it is remembered that the Punjab is considered a rich province, whilst C.P. is considered poor. Though both have about the same agricultural area, the Punjab produces more than double the C.P. Leaving aside Assam and N.W.F.P. which have very special geo-physical characteristics, the range between the remaining 9 provinces is enormous, the highest figure being as much as six times the lowest. The abnormally low cart population in N.W.F.P. and Assam and to a certain

extent, Sind, can be explained by the nature of the terrain which either due to mountainous, desert, or dense jungle conditions, militates against agricultural exploitation of the land.

10. One would expect some uniformity about the number of carts per 1000 tons of produce but here the variation is greatest, C.P. being 37 times as much as NW.F.P. and 6 times as much as the Punjab. The latter is surprising since these provinces produce nearly twice as much per square mile (line 47) as C.P. It cannot be explained by the supposition that one province produces more in the way of money crops than the other, because the opposite holds true between the Punjab and C.P. and there is conflicting relation between the production of money crops and the incidence of carts amongst the other population.

11. The difference can, therefore, only be explained by assuming that in certain regions carts carry more and/or work for greater number of days in the year than in others. Such an inference seems to be supported by the great variation in the number of bullocks per cart (line 71). For instance, in the Punjab which produces a study draught animal, there is a population of about 12 animals per cart, whilst in C.P. where animals are small the figure is $3\frac{1}{2}$, a proportion which may at first sight appear to be contradictory. Comparisons of figures for other provinces, specially U.P., Bihar, Bengal and Madras show that there are too many variables to permit of general conclusions. It is revealing that the only average which shows a remarkable uniformity amongst all the Provinces is the figure of average production per head (line 49). The agricultural production for the whole of India, food grains plus money crops, amounts to the low figure of $5\frac{1}{2}$ maunds yearly, barely half a seer of food grains a day per head.

12. Engineers need no warning about the care with which averages are to be used for coming to any conclusion. Thus whilst the average village population, (line 30) should be regarded with caution, the averages in lines 3, 6, 9, 12, 15 and 18 are accurate and interesting and those in lines 24 and 27, practically meaningless. Similarly, the figure of average expenditure on roads, which is the average expenditure per mile for all roads, both metalled and unmetalled (line 59), should be taken as no more than indicating whether a province is hot or cold on its roads, and even then it gives no indication of extent or adequacy of the road system.

13. The moving of agricultural produce is after all the main reason for the existence of the cart and this produce may properly be taken as a fair index of its work. Averaging this produce, especially between high and low value crops, say from bajra to tea, must therefore be accepted with this fact in mind. With this reservation, one would not go far wrong in taking this average as a fair comparative measure of the work that the bullock cart is called upon to perform. It is true, it is not always carrying the final product of farming and is working on numerous other errands in the course of its existence ; on the other hand, not all the agricultural produce of the country finds its way to the market or the railway. Indeed, it would appear from the average production of half-a-seer per head, per day, that the major portion of the grain produced must be a subsistence crop.

14. One is not far wrong in assuming as a rough generalisation, that the total extent of rural cart transport is equal to the total agricultural production This is corroborated by the figure for total goods transported by the Indian railways which averaged 105 million tons annually for the 10 years preceding the war. Of this, about 25 million tons was coal alone The railway figures are for traffic in both directions, that is to and from the ports, and amount to approximately double the agricultural production of British India. A valuable check on the extent of traffic by cart would be provided if figures were available of the total railway traffic originating and arriving in a district To ascertain this for each district would perhaps entail too much labour, though it is conceivable that this may be worth while, for instance, for a proper appreciation of road competition or of deficiency in rural communications and similar investigation It would serve our purpose however if this information was available for districts in which it is proposed to carry out the cart survey. Unfortunately information connected with railways is usually collected and published by systems or units of railways and it is difficult to get figures by areas. Traffic figures even for whole Province are not readily obtainable and it has not been possible, therefore, to give in the annexed table anything but the total railway milage by Provinces; it has not been possible even to indicate separately Class I and Class II railways.

15. In connection with the railway milage in each Province, it is interesting to note that the figures of average area of agricultural land served per mile of railway show an unexpected degree of uniformity. This is surprising in the face of the large variations between Provinces in the density of population, in production per square mile, and especially the great variation in road milage per unit of population or of area With the exception of Sind, a considerable portion of the railway milage of which is a corridor to the North, there is also a fair uniformity in the figure of produce for each Province per mile of railway.

16 The railway system of India would seem to be better planned than the road system which shows great variation between the Provinces, in the road available for the same amount of produce or the same numbers of people. It is perhaps in this particular aspect that the warning against averages uttered in para 12 is most apt The average of a mile of metalled road per 6 2 square miles of agricultural land would not be considered bad by the standards of other agricultural countries, only it must be remembered that the metalled milage does not serve agricultural area alone and that the quality of metalled road in one region may be very different from that in another A curious coincidence is that the average for the Punjab, the Province with some of the best roads in India, should be the same as that for Bengal, reputed to be one of the Provinces most lacking in roads.

17. The average amount of produce, and hence transport, for a bullock cart, is shown to be 250 maunds (line 53) , at the highest (omitting N.W.F.P., and Assam), it is 500 maunds and the lowest, 100 maunds At the most this would mean an average of ten to twenty trips for a cart in a year. This makes one doubt if there is a bullock cart problem. Of course, the problem exists because we have all been concerned, at one time or another, at the havoc caused on roads within our charge by the bullock

cart. But what length of the 70,000 metalled miles of India is subject to this grinding and how many of India's seven million carts are the offenders ?

18. There is no data on which a conclusion can be arrived at or consideration based and all the necessary information has to be collected. Hence the necessity of a bullock cart survey (not census) for India. It is required to know, what types of carts there are, what they carry, how many days they work, how many days they use the roads, how many are the property of professional cartmen, what are the materials and dimensions of their tyres, etc., before a considered opinion can be formed on the extent of the bullock cart problem and the measures to meet it. The Indian Roads Congress has attempted to collect through members of the Council, sketches or diagrams of the types of carts in common use within the sphere of their activities. Sketches for about 60 types of wheels and carts have been received from all Provinces except Madras and from some States and are filed in the office of the Indian Roads Congress. This information is by no means exhaustive, the chief lack being particulars of tare weight and carrying capacity, and it only serves to show the very great diversity of types that may be expected.

19. A census of the six million odd carts in British India to obtain these particulars would mean enormous labour, expense, and a lot of time ; results, however, to practically the same degree of accuracy can be obtained by a properly conducted random sample survey Mr. Yeatts, Commissioner for the 1941 Census, informs the author that random sampling of 1 in 50 frequently gave results within one-half per cent of the full count. For the purposes of a correct appreciation of the bullock cart problem, no such high degree of accuracy is required.

20. No survey of bullock carts and their working can be complete without particulars of the bullocks also Regarding their draught capacity, the author is informed by the Animal Husbandry Commissioner that the height of the animal behind the hump is a simple and reliable working index of the animal's pulling power. This height is measured in inches. During the course of survey, it would be a simple matter to enumerate the number of working bulls and their height.

21. If 1 in every 200 of the 6½ million bullock carts in British India is to be counted, over 30,000 carts would have to be surveyed. Assuming that an enumerator can survey four carts in an hour, he would be able to deal with 20 carts in a day, allowing for time to get from village to village. This means about 1600 man-days for the work. If 20 enumerators were employed the count would be made in 80 days, say four months allowing for transfer from area to area, rest days etc. The problem is therefore one of quite manageable proportions.

22. It would be obviously impracticable to so average a census throughout the length and breadth of India that every 200th cart throughout its six million was picked up by the enumerator. Some sort of selection sampling is obviously called for. The problem is how to make such a selection fully representative and at the same time praticable. The object of this paper is to obtain a discussion on the possible means of assuring this.

23 One way would be to pick every 200th village and make a full enumeration of the carts in the selected villages The number of villages to be surveyed in each of the province, on this basis, with the approximate number of carts, and the time in man-days, would be :

	Villages	Carts	Days		Villages	Carts	Days
N.W.F.P.	150	300	15	Bihar	350	2500	125
Punjab	180	1700	85	Bengal	420	4300	215
U.P.	500	5100	270	Bombay	110	3400	170
Sind	30	450	22	Madras	180	6300	315
Assam.	170	350	17	C.P	200	5600	280
Orissa	140	900	45	Total	20430	31200	1560

From the above list, it appears that whilst to some provinces like the Punjab and U.P , too little time is given, too much is given to others, say C P. The following 'weighted' figures may therefore be accepted for the number of days required, including wasted days in each province.

N.W.F P	20	Sind	40	Bihar	200	Madras	420
Punjab	200	Bombay	250	Bengal	300	Orissa	100
U.P.	320	C P.	200	Assam	40		
Total	540		490		540		520

The grouping also shows a convenient way of dividing up the whole continent into four territories, roughly North, West, East, and South.

24 Nearly 2500 villages picked at random throughout India ought to give a very representative sample It is possible, however, in such an arrangement, an unduly large amount of time is spent in travelling to the selected villages distributed over a whole province Another method would therefore be to select the villages with some idea of geographic convenience. Though not as strictly accurate as the first method, there should be no material difference in the result if care is exercised to select samples from representative areas.

25. An advantage of either of the above methods would be that a complete count of the bullock carts in a village would be taken and the results compared against the All-India Live-stock Census The regularity in the totals for several years as well as uniformity and inter-dependence in the figures in this Census may be considered as internal evidence of accuracy All the same it is advisable to reserve opinion upon this internal evidence until the method of enumeration has been verified. For instance, uniformity might result from extensive copying of the previous record for the purposes of fresh enumeration.

26. A third way of taking the count would be to move quickly from village to village going through more villages, but to take the particulars of a few carts only. In one way it may take more time, as more villages would have to be 'educated' during the process of extracting information, but it may be quicker in another way, in that no time need be taken up on obtaining a thorough count and extracting information.

27 No statistician will accept a sample as representing the whole, unless the results are substantiated by a full count for part of the investigation. Though a high degree of accuracy is not necessary for our purposes, i.e. to ascertain the use and abuse of the road and the remedial measures required, a full count would be useful in establishing accuracy

and to ascertain the reliability of the Live-stock Census. If this is considered desirable, the sampling should be by area or unit, but within such area or unit the count must be complete. There must also be a full count in a larger area or unit which would include a fair number of smaller ones.

28. The choice of method will also be influenced by the amount of information it is desired to collect in addition to the bare physical particulars of the carts, such as details of ownership, extent of professional carting in a village, number of days worked, extent of milage on pucca roads, katcha roads and in farm work etc. Such information can be of the utmost value and the opportunity for obtaining it should not be missed, if a cart survey is undertaken. But zeal should be tempered with discretion, otherwise there is the danger of defeating the object of the census by trying to cram too much into the inquiry.

29. No scheme of statistical survey ought to be launched without first putting through, what might be termed a 'pilot' scheme. This scheme would be a replica on a small scale of the main scheme, or it may be a small portion of the actual scheme. The object is to discover in time, how the scheme will proceed, how labour may be saved at some stage or another, what snags one is likely to be run into and to get an advance picture of the final result so as to plan ahead its analysis and any modification in questionnaire demanded by such analysis.

30. In drawing up a questionnaire it is necessary to bear in mind that whilst the opportunity of making the inquiry as comprehensive as possible should not be lost, this object will not be served by making the questionnaire too lengthy and detailed. It is therefore necessary to decide beforehand what aspects of the inquiry are most essential and then judge what further information can be elicited concurrently without clouding the main objective. The method of asking the question is also almost as important as the question itself The man to be interrogated will be the village peasant and not only must his mental limitations be kept in mind, but also the villager's natural suspicion of any interrogation. The capacity and psychology of the enumerator or interrogator also requires equal study because on him depends the translation of replies into a factual record. The questionnaire should therefore be as simple as possible, every question should be carefully considered so as to be without any ambiguity. A question should be incapable of more than one construction being placed on its meaning, and must be capable of being answered simply and directly. Questions should be so worded as to invite answers that can be recorded as a figure or a yes or no or as a statement limited to four or five words

31. In order to judge the abuse, it is necessary to know the use made of the road by the bullock cart, and the primary object of the inquiry would be to determine the use and abuse of the road. It would therefore be necessary to enumerate the following particulars for this purpose.

Tyre material and width,
Weight unloaded, and carrying capacity; possibly, size.
Extent and number of journeys, (on metalled and unmetalled road separately).

To get proper information about tyre conditions, it would be necessary to obtain wheel diameter and method of spoking. Hub and axle dimensions would also be relevant A moote point is whether the method of supporting the axle should be enumerated or not. With the type and carrying capacity, it would be necessary to ascertain the number of animals employed for draft and the number of wheels.

32. A secondary, but quite important aspect of the use of the road is the purpose for which the road is used and the type of user For this, it would be useful to know the proportion of professional cartmen, the proportion who engage in carting in the slack season, and the proportion of owners with more than one part, also to what extent carts are owned by large land owner and if these are leased to their tenants Care is specially due under this head, not to make the inquiry too elaborate.

33 A valuable by-product of a bullock cart survey would be a picture of the extent or otherwise to which villages are served by roads. This could be obtained by recording the distance of each village visited from the nearest public road and the length of metalled and unmetalled road traversed before reaching a market town or railway station. What portion of his produce is retained in the village and what portion carted to the market? Questions will have to be carefully worded so as not to confuse the enumerator and so that "wild guesses" by villagers are not recorded as facts.

34. The second most important objective of the survey would be to obtain information on which decision could be arrived at about conversion to pneumatic tyres Though it may be inopportune to talk about rubber tyres at the present time, development in this direction is bound to come after the war That it should be encouraged no one will doubt, but to what extent, and whether it should be forced, subsidized or otherwise artificially fostered, can only be decided from such an inquiry The pneumatic tyre scores in every way, except under wet and muddy conditions It decreases the draught required and increases carrying capacity, (a) because of the smaller road resistence and (b) because of the more efficient axle bearings Against this are its initial higher cost, necessity for maintenance, and deterioration when standing idle, especially in a deflated state When agricultural produce averages only 5½ maunds per head and about 270 maunds per cart, what will the peasant do with the increased capacity? Knowledge on the following points would be a factor in arriving at conclusions

How much use in wet and muddy conditions?
What are the idle periods and of what length?
Can increased carrying capacity be utilised?
Particulars of existing axles, hubs, the wear on these, their efficiency, lubricating etc.

35. On the other hand, supposing it were possible to partially rationalize the work of the cart so as to bring the load factor to say 50 tons a year, not an unreasonable figure, two million would suffice for all the cart transportation in India moving on public roads. If the whole of this number were to be put on pneumatic tyres, it should be possible to

Characteristics :—Well graded material with excellent binder: Highly stable under wheel loads, irrespective of moisture conditions: Functions satisfactorily when surface treated or used as a base for relatively thin wearing courses: High internal friction and cohesion ; no shrinkage, capillarity or elasticity.

Group A 2.—Grading : Not less than about 55 per cent of sand in the soil mortar.

Constants : *Liquid Limit* generally not less than 14 or greater than 35 ; a plasticity index of zero with a significant *shrinkage limit* or a plasticity index greater than zero and less than 15 with or without a significant *shrinkage limit, centrifuge moisture equivalent* not greater than 25.

Characteristics :—Coarse and fine materials with an inferior binder: Highly stable when fairly dry : Likely to soften at high water content caused either by rains or by capillary rise from saturated lower strata when an impervious cover prevents evaporation from the top layer or to become loose and dusty in dry weather . High internal friction : May have detrimental shrinkage, capillarity or elasticity.

Group A—3 Grading: Effective size not likely to be less than 0.01 m.m.

Constants :—*Liquid limit* not appreciably greater than 35 ; no *plasticity index* , no significant *shrinkage limit; centrifuge moisture equivalent* less than 12.

Ability of sands to resist sliding when wet, indicated as follows: *Liquid limit* of 10-14 signify beach and other rounded sands which slide easily; *liquid limit* of 30 to 35 indicate rough angular particles which do not slide easily. In addition, *liquid limit* when lower than *field moisture equivalents* indicate materials which flow under partial saturation; when equal to the *field moisture equivalents*, the *liquid limit* indicate average sands which flow under full hydrostatic uplift. *Liquid limits* greater than *field moisture equivalents* indicate rough grained sands which flow only when in a state less consolidated than that represented by the *field moisture equivalent*.

Characteristics :—Coarse material only, no binder : Lacks stability under wheel loads but unaffected by moisture conditions : Not likely to heave or shrink appreciably : Furnishes excellent support for flexible pavements of moderate thickness and for relatively thin rigid pavements : High internal friction, no cohesion : No detrimental capillarity or elasticity.

Group A-4. Grading : Less than 55 per cent sand.

Constants : *Liquid Limit* seldom less than 20 or greater than 40; *plasticity index* not greater than those indicated by Curve 3 of Fig.2; *shrinkage limit* not likely to be greater than 25; *centrifuge moisture equivalent* approaching those indicated by Curve 10 of Fig. 4 between 12 and 50; when greater than *liquid limit*, indicates varieties of soils inclined to be especially unstable in the presence of water; *field moisture equivalent* equal to or somewhat greater than those indicated by curve 11 of Fig. 5, with a maximum of about 30.

Increase in expansive properties generally indicated when *shrinkage limits* exceed 20 and approach those represented by Curve 6 of Fig. 3, especially likely when field moisture equivalent exceeds *centrifuge moisture equivalent*

Characteristics —Silt soils without coarse material, and with no appreciable amount of clay Tendency to absorb water readily in quantities sufficient to cause rapid loss of stability even when not manipulated When dry or damp, presents a firm riding surface, which rebounds but very little upon the removal of load Apt to cause cracking in rigid pavements due to frost heaving, and failure in flexible pavements due to low support Internal friction variable; no appreciable cohesion or elasticity Capillarity important

Group A–5. Grading Less than 55 per cent sand. (Exceptions occur).

Constants. *Liquid Limit* usually greater than 35, *plasticity index* seldom greater than those indicated by Curve 3 of Fig 2, *centrifuge moisture equivalent* greater than 12, often lying between Curves 9 and 10 of Fig 4, not likely to water-log. (Exceptions occur). *Shrinkage limit* generally greater than 30 and greater than 50 for very undesirable members of this group · May approach values indicated by Curve 6 of Fig 3 for silts containing peat and approach those indicated by Curve 7 of Fig 3 for soils containing either diatoms or mica in appreciable amount · *Field moisture equivalent* approaching those indicated by Curve 12 of Fig. 5 for silts containing peat in appreciable amount and those indicated by Curve 13 of Fig 5 for highly elastic soils containing mica or *diatoms* in appreciable amount The *kaolins*, representing good binders, are members of group possessing relatively high *plasticity indices* and low *field moisture equivalents*

Characteristics ·—Similar to Group 4, but gives highly elastic supporting surfaces with appreciable rebound upon removal of load when dry. Elastic properties interfere with proper compaction of macadams during construction and with retention of good bond afterwards. Appreciable elasticity.

Group A-6.—Grading · Seldom contains less than 30 per cent clay.

Constants :—*Liquid limit* usually greater than 35, *plasticity index* approximately represented by Curve 4 of Fig. 2, *shrinkage limit* not likely to be apppreciably greater than that indicated by Curve 5 of Fig 3, *centrifuge moisture equivalent* test generally productive of water-logging, likely to lie between Curves 9 and 10 of Fig. 4, *field moisture equivalent* seldom exceeding those indicated by Curve 11 of Fig. 5; but may be appreciably less for certain colloidal soils · Volumetric change generally greater than 17

Characteristics.—Clay soils without coarse material In stiff or soft plastic state absorb additional water only if manipulated · May then change to liquid state and work up into the interstices of macadam or cause failure by sliding in high fills. Furnish firm support essential in

properly compacting macadams only at stiff consistency: Deformations occur slowly and removal of load causes very little rebound. Shrinkage properties combined with alternate wetting and drying under field conditions are apt to cause cracking in rigid pavements: Low internal friction; cohesion high at low moisture content, no elasticity; possible detrimental shrinkage.

Group A-7.—Grading: Seldom contains less than 30% clay.

Constants: *Liquid limit* usually greater than 35; *plasticity index* varies between those indicated by Curves 3 and 4 of Fig. 2; *shrinkage limit* generally varies between those indicated by Curves 5 and 6 of Fig. 3; *centrifuge moisture equivalent* varies between those indicated by Curves 9 and 10 of Fig. 4; water-logging in *centrifuge* test may not occur even at very high *moisture equivalents. Field moisture equivalent* greater than those indicated by Curve 11 of Fig. 5· Relatively low *shrinkage limit* with high *field moisture equivalents* indicating presence of colloidal organic matter: Relatively high *shrinkage limit* indicate the possibility of frost heave.

Characteristics:—Similar to Group A-6, but when moist, deforms quickly under load and rebounds appreciably upon removal of load: Thus, lacks firmness in support, similar to subgrades of Group A-5. Alternate wetting and drying under field conditions leads to even more detrimental volume changes than in Group A-6 subgrades: May cause concrete pavements to crack before setting and fault afterwards. May contain lime etc. productive of flocculation. Possesses elasticity.

Group A-8.—Grading: not significant.

Constants: *Liquid limit* greater than 45, *plasticity index* generally less than those indicated by Curve 3 of Fig. 2; *shrinkage limit* indicated approximately by Curve 6 of Fig 3, *centrifuge moisture equivalent* between Curves 9 and 10 of Fig. 4; *field moisture equivalent* likely to be greater than those indicated by Curve 12.

Water-logging in the *centrifuge test* is characteristic of the mucks containing clay and colloids, whereas very high equivalents without water-logging are characteristic of peat not more than slightly decomposed

Characteristics:—Very soft peat and muck incapable of supporting a road surface without being previously compacted or displaced by a fill. Low internal friction and low cohesion. Apt to possess capillarity and elasticity in detrimental amount.

PART II

SOIL CHEMISTRY AND PHYSICS

CHAPTER 2.

CHEMICALLY ACTIVE SOIL CONSTITUENTS AND THEIR IMPORTANCE TO THE SOIL ENGINEER.

Fractions larger than silt are chemically inactive. Silt may be slightly active especially if free salts of the alkali or alkaline earth bases are present By far the greatest activity is to be found in the clay fraction especially that portion below 0.001 m m known as colloidal clay, i.e., clay which has certain marked colloidal properties Actually these properties are not always, if ever, complete, so that it is not strictly correct to refer to this fraction as soil colloids.

Most of the deleterious characteristics of a soil, which involve directly or indirectly moisture relationships, depend upon the amount and the nature of the clay fraction and hence on any changes in the nature of the clay complex which may occur. In nature, chemical actions, both ordinary and by base-exchange, may occur in many soils under normal conditions, during the year cycle. Such actions may lead to a cyclical or permanent change in the soil's properties Under artificial conditions, such as when the soil is covered by some form of foundation slab the change in properties may be abrupt and will almost certainly be of a permanent nature.

It is therefore essential that certain chemical and physico-chemical properties of the soil should be clearly understood. This involves some fundamental conceptions of soil chemistry and physics which are now presented.

CHAPTER 3.

THE SILICA-SESQUIOXIDE RATIO

The silica sesquioxide ratio or ratio of the silica content to the ferric oxide plus aluminium oxide, usually expressed as *S/R*, is of considerable value in soil studies. At one time it was thought that this ratio could be made the basis for a strict classification of soils but unfortunately under the present definitions and test procedures, this has not yet been found wholly practicable Examples have been met in which two clays of differing constitution gave the same *S/R* ratio[3]. However, as regards the main soil groups, Reifenberg was able to find, from a study of published data, that each of these main groups was represented by a fairly distinctive *S/R* ratio[3] His average figures were :—

Grey Desert Soils	..	..	3.62
Prairie Soils and Tschernozems		..	3.17
Alkali Soils	..	..	3.01
Podsols	..	..	2.84
Terra Rosa	..	..	2.43
Red Desert Soils	..	..	2.08
Brown Earths	..	..	1.98
Tropical Red Earths	..	..	1.73
Lateritic Soils	..	..	1.28

The figures given by Byers[17] are very similar to these.

Since the weathering process is only truly reflected in the secondary clay mineral matter, it is usual, in modern analyses, to determine this ratio for the colloidal clay fractions although formerly it was determined for such fractions as those passing the 2 m. m. sieve.

Unfortunately the *S/R* ratio cannot, apparently, be used for the determination of the predominant clay type with any degree of certainty.

Clarke, Rieken and Reynolds[71] discussing the "Importance of the 2-Micron Fraction" say :—"The number of constituents "—(*quartz, calcite, kaolinite, beidellite, muscovite* and possibly *montmorillonite* etc.)"—present in the 2-micron fraction will necessarily invalidate its use in many respects. ....The mineral complexity of the fine fraction of the soil presents a problem of great magnitude and it is certain that no fraction of the soil, no matter what the particle size limits are, will be entirely free of considerable heterogeneity of constituent composition. Marshall[5] has adequately discussed the nature of the complexity of the fine fraction of the soil and states that 'the ratio of the silica to sesquioxides does not necessarily indicate even roughly the predominant clay type' ".

CHAPTER 4.

SOIL ACIDITY

The acidity or alkalinity of an aqueous soil solution may be represented by its *pH* value, that is, by the negative logarithm of its hydrogen-ion concentration.

Electrolytic Solutions, including pure distilled water, dissociate, to a greater or lesser extent, into their *cations* and *anions* and thus exhibit electrical conductivity. Thus, for pure water, :—

$$H_2O = H^+ + (OH)^-$$

The concentration of H^+ ions in a litre of pure distilled water has been found to be approximately :—

$C_H = 10^{-7}$ gramions per litre, for which the negative logarithm, or *pH*, equals 7.

Further, since pure distilled water is neither acid nor alkaline, the hydroxyl ion dissociation must equal the hydrogen ion concentration. This follows since, by definition, an acid solution must have an excess of H—ions over (OH)—ions and an alkaline solution must have an excess of (OH)—ions over H—ions,

$$\text{or, } C_{OH} = C_H \equiv pH = 7.$$

The value of pH = 7 is therefore an expression of neutrality.

(5) Marshall, C. E "The Importance of the Lattice Structure of the Clays for the Study of Soils", Soc. Chem. Ind. 51 (1935).

For any aqueous solution the product —

$C_H \times C_{OH}$ = constant = 10^{-14} at a temperature of 21 degrees centigrade [10]

Any solution, and in particular any aqueous soil solution, will be acid or alkaline according as whether.

$$C_H \gtrless C_{OH} \text{ or, } C_H \gtrless 10^{-7}$$

Examples of weak acid and alkaline solutions with their corresponding pH values :—

(a) Acid — $\frac{N}{10}$ HCL — 85% dissociated.

$$C_H = \frac{85}{100} \times \frac{1}{10} \text{ gms. H-ions/litre} = 10^{-1} \text{ approx}$$

or, pH = 1.0 approx.

(b) Alkaline — $\frac{N}{10}$. *NaOH* — 84% dissociated.

$$C_{OH} = \frac{84}{100} \times \frac{1}{10} \text{ gms. (OH)-ions/litre}$$

$$= 10^{-1} \text{ gms (approx) (OH) ions/litre}$$

$$\text{or, } C_H = \frac{10^{-14}}{10^{-1}} = 10^{-13} \text{ gms. (approx.)H-ions/litre}$$

for which *pH* = 13 (approx)

The acidity or alkalinity of a solution may be determined by either *of the following two principal methods of which the latter is by far the* more common —

(a) By titration with normal acid or alkali to neutrality, or,

(b) By determination of the pH electrolytically using the platinum, glass, quinhydrone or antimony electrode method. The antimony electrode method seems to be the latest and details are given in a paper by C J Schollenberger contained in Soil Science, Vol. 41, 1936

The *pH* of a Soil varies with :—

(a) The amount of organic matter of humus present and its degree of base saturation, i.e. with the colloidal humic substances present and the amount of bases absorbed therein.

Humic acid, formed during the decomposition of organic matter, is, in the absence of bases, highly acidic having a *pH* of 4 or even less. It is oxidizable especially in the presence of bases, producing CO_2 and H_2O When bases are present, especially calcium, the acid properties of humus vary from 'mild' to neutral.

(b) The amount of mineral acids present. The chief mineral acids present, or likely to be present, in soils are :—

$H_2O + CO_2$ acting as H_2CO_3, formed during the oxidation of organic materials and humic acid or by the dissolving in water of carbon dioxide from the atmosphere during rain or formed from the carbon dioxide produced during plant and micro-organic respiration in the presence of moisture[11], and introduced into the soil by percolation.

H_2SO_4 formed during the oxidation of organic sulphur compounds, sulphides and free sulphur by certain bacteria and also by direct oxidation of sulphur compounds and sulphides[3,11].

HNO_3 formed during thunderstorms, especially under tropical conditions, and introduced into the soil by percolation.

In addition, phosphoric acid and/or a form of silicic acid may be formed, under certain conditions, by anion exchange[12].

Further, potential HCL, H_2SO_4 and H_2CO_3 may be formed during partial cation exchange in the presence of electrolytic solutions in which the base replaces H-ions from the soil complex or micelle

According to some authorities the amounts of mineral acids present in soils are small but this does not appear to be universally accepted.

(c) The nature of the clay—especially the colloidal clay-fraction. This is expressed by the *silica-sesquioxide* ratio or the *acidoid-basoid* ratio for the clay fraction, i.e. $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ or, in view of the work of Mattson, Pugh and du Toit and others, and as expressed by Robinson[3], by the (silica, P_2O_5, humic acid)/(sesquioxide) ratio when humic acid is present in the colloidal clay complex.

Thus desaturated siliceous clays, i.e. clays in which the silica sesquioxide ratio has been, perhaps arbitrarily, fixed as greater than 2, have a lower pH than desaturated clays rich in sesquioxides, i.e. those clays in which the silica sesquioxide ratio is less than 2[3].

In the above it is pointed out that silica and the sesquioxides not only form the bulk of the clay fraction but offer the greatest resistance to base exchange and other weathering phenomena. The degree of permanentness is $Fe > Al > SiO_2$.

(d) The degree of base saturation of the silt, clay and colloidal clay fractions. The higher the degree of base saturation the higher the pH, but unless some soil alkali or alkaline earth bases, preferably in the carbonate form, be present in free and accessible form the pH is unlikely to rise much above the neutral value of $pH = 7$.

Similarly the lower the base saturation or the higher the degree of unsaturation the more acid the soil-reaction

The pH of a soil supplies the engineer with the following information :—

1 Low values of the pH indicate soils with an acid reaction Any free or ionized potential acid is available to attack exposed steelwork and may, by capillarity, or possibly by vapour transmission, be able to attack steelwork embeded in concrete. This action is rather similar to that occurring when the reinforcement of piles in sea water is corroded by acids formed electrolytically due to temperature differences and introduced to the surface of the reinforcement by capillarity, vapour flow or by electric currents.

2. Requirements in the control of water purification[13].

Apart from the above the pH gives little direct information unless accompanied by further data, as will be seen from the following —

3. High values of the pH infer alkalinity. Though generally speaking an increase in pH corresponds to a decrease in corrodibility yet if free carbon dioxide be present an alkaline solution may cause as much corrosion as an acid solution [14]. Normally an alkaline solution will lead to deposition in, say, a pipe line and cause choking.

4. The pH value is an indication of the base exchange capacity or, more correctly, of the degree of saturation From its value and a knowledge of the nature and amounts of replaceable bases the amounts of such stablizing materials as calcium chloride, sodium chloride and silicates required to be used in earth road stablization problems, can be estimated for known conditions of leaching. This will be further discussed under Base Exchange.

5 The pH gives some indication of the active weathering process and of the nature of the clay minerals formed by that process. Thus a low pH indicates an active acid weathering productive of siliceous clays ($S/R > 2$) of high plasticity, low friction, high cohesion and moderate shrinkage ; a neutral or slightly alkaline pH in the humid tropics indicates strong hydrolytic weathering productive of sesquioxide clays ($S/R < 2$) of low plasticity, moderate cohesion (down to a certain moisture content below which the cohesion disappears) and low shrinkage , a high pH indicates a mild hydrolytic weathering and represents fine grained impermeable soils of high cohesion and high shrinkage. The clay minerals for the above progression of weathering degree may, in general, be theoretically considered to vary from those bordering on the *Montmorillonite* group down to those represented by the *Kaolin* group and/or the hydrated aluminium, ferric oxide group. In practice, however, the dominant clay minerals appear to be represented in rather the reverse order, i. e., minerals of the *montmorillonite* group appear to be more common in tropical than in temperate zones and that those of the *Kaolinite* group appear more common in temperate zones

When the S/R ratio approaches 2, the weathering borders on both the podsolic and lateritic, or, on the siallitic and allitic systems. The two may actually be both active in any one area. This leads to two possibilities—a variation in profile properties within the area and

43. Give the average lengths of travel per day.

(a) On metalled roads

(b) On unmetalled roads.

44. Give the number of professional cartmen owning more than one cart.

45. What is the total weight carried by professional carts in a year?

III. GENERAL.

46. Give particulars of the chief obstacles to the satisfactory operations of carts, such as loose surface, mud, sudden humps or dips, nullah crossing and their approaches, gradients, or any other special difficulties.

47. How many additional carts will use the roads if these defects are removed?

48. How many additional days and miles will each cart work, or additional load it will carry if the defects are removed?

49. Total quantities in a year carried from villages—

(a) To Railway Station. Mds.

(b) To markets. Mds.

50. Give details of

(i) Any periodical markets, fairs etc held in the village;

(ii) the average number of outside carts coming to the market from neighbouring villages and towns;

(iii) the total value of transactions in each market day.

. (a) State particulars of any industries in the village, with approximate quantities produced and value;

(b) Give particulars of raw material with quantity imported from outside for these industries

(c) Give lengths of metalled and unmetalled roads, used by carts getting the raw materials;

(d) Give particulars and quantities of the finished product exported to each place with names of places

52 Can new industries be opened or existing industries improved by better roads ?

53 Give the average number of idle days with reasons i e. bad communications, weather or lack of materials for transport—
(a) Agriculturists.
(b) Professionals

54. What are the prevalent rates of carriage per mile per maund—
(a) On kutcha roads,
(b) On metalled roads,
(c) Combined.

IV CONVERSION TO PNEUMATIC TYRES AND OTHER TYRES.

55. Give number of carts with pneumatic tyre equipment, and state who owns them and what work they do, and weight carried, and the number of months the carts stand idle.

56 Give number of cart-owners willing to substitute pneumatic tyres for their carts and on what terms

57. Is there need for increased capacity per cart for carting produce etc. from and to village ?

58 Are there any other carts with roller bearings ?
Give number; What work they do and the weight carried.

(*a*) British India includes the 11 Governors' Provinces as well as Baluchistan, Delhi, Ajmer and Coorg.

(*b*) It would be meaningless to strike averages in tons over 100,000 population because of the large variation.

(*c*) These provinces did not participate in the 1940 live-stock census.

(*d*) Carts in urban and rural areas were not counted separately in Bihar.

(*e*) and (*f*). These totals, for the provinces where separate enumeration was carried out, are 282, 267 and 4,181,785 respectively or 5·65 and 94.35% respectively.

(*g*) Not accurate.

Tuesday, October 15th, 1943.

Mr. Mahabir Prasad (Chairman) Called upon Mr. Vesugar to introduce his paper "proposals for an All-India survey of Bullock-Carts by means of random sampling".

The above paper was taken as read.

DISCUSSION

MR. VESUGAR (Author) in introducing his paper said:-The most attractive feature to me of the Gwalior session of the Indian Roads Congress is the way our interests have ranged from flights of fancy to the daily grind. We have talked about reconstruction when we are united in feeling that this shall not be on the scale of a paltry 50 crores but have argued whether it should be a grudging 100 crores or a solid 300. On the other hand we have kept our feet firmly on the ground; we have discussed the old and humble macadam and are now going to talk about the older and humbler bullock cart. I need not, therefore, apologise for introducing a paper which has no claim to originality or research and which is not a contribution to engineering as a science.

Whilst no engineer denies the destructive action of the iron tyre, it is possible that the total extent of this damage may be greatly exaggerated. Depending upon the extent of this damage the remedy will lie in converting roads subject to such damage to concrete or to converting bullock-carts in certain localities to rubber tyres. We cannot get a clear idea of the solution until we know the problem accurately. Such figures and statistics as are readily available bring out some curious facts and serve, if anything, to increase the perplexity in one's mind rather than solve it. It will be seen from the figures quoted in paragraph 8 (page 186) that there are some very grave variations but at the same time there are also some distinct trends. The amazing thing is that one finds the greatest variation where perhaps one would expect uniformity, for instance the number of carts per 1000 tons produce.

The table at the end of the paper is by no means exhaustive nor should every figure given therein be considered strictly accurate. I notice that certain mistakes have already crept in during printing e.g. Sind (line 7), or Central Provinces (line 48); there may be many others which may have escaped notice. But on the whole the table may be considered to represent a fairly accurate picture for British India as a whole and if it is incorrect in the extent or the assumptions regarding a certain figure, the error is the same for all provinces and the picture is not, therefore, materially vitiated. Uniformity all over India is perhaps only visible in the case of the figures and averages concerned with railways. Not only are the agricultural areas served per mile in each province comparatively uniform, but so are also the figures for population per mile of railway and the produce carried. If this means anything, it shows that the railways have been carefully projected This may serve as a pointer to us in designing our Road net.

Perhaps, to our shame as road engineers, it may be stated that averages concerning roads are likey to be the most misleading. This is a strong reason for the establishment of a bureau for collecting road statistics. The most uniform figure in the whole table seems to be that given in line 49. Translated, this figure would mean that the total produce all over India is about 1 lb. per head per day, just enough for a bare subsistance leaving very little surplus for money purchases out of agricultural produce.

In para 12 [page 187], I have drawn attention to the danger of making deductions from averages and the danger of over-simplifications of facts. Nevertheless such averages do show broad trends In paragraph 17 [page 188] it is worked out that the average number of trips for a cart per year are only 10-20. This would mean that the bogey of damage by the bullock-cart is very much exaggerated. All the same we have seen this damage with our own eyes and therefore, there is all the more reason for a statistical survey to find the reason why. If we could come to some final recommendations regarding the lines on which the survey should proceed half the problem will be solved. The next step after deciding the method is to try out the method by means of a pilot survey (we have heard rather a lot about pilot surveys during this session and sometimes I wish I had not coined this word). Before any work can be undertaken it is necessary to decide upon the questionnaire. Admittedly the one proposed at the end of the paper has become too long in trying to make it comprehensive It has been drafted to make certain that nothing is left out, the difficulty comes in deciding what to leave out.

An important by-product of a bullock-cart survey would be to obtain a picture of the extent to which villages are served by or starved of road and to collect information which would help in projecting future village road construction.

I am afraid statistics are often distrusted. That is no argument that honest investigation of a problem can be carried out without statistics It is said that truth lies at the botom of a well, who knows it may lie at the bottom of a statistical table.

Mr. Kynnersley (Bombay):—Mr. Vesugar should be congratulated on bringing out an enormous number of very interesting facts He may be criticised for taking many of the facts which are not directly connected with bullock-cart, but he has given very valuable analysis at the end The only trouble is that when I tried to understand this analysis, I got rather appalled with the maze of figures I do not know whether it is so with the majority of persons. Personally, I do think of traffic in terms of the miles per square mile of area. If you turn to the table at the end, you will see there items 60 and 61, agricultural area per mile of metalled roads and agricultural area per mile of all roads If you read through these things, you get a certain amount of information, but I suggest to Mr. Vesugar that the meaning of this will be more easily understood in terms of milage of metalled roads, and of all roads per square mile of area.

From an analysis of the figures furnished, it is seen that the milage of metalled roads per square mile of agricultural area works out as under :—

		Milage per sq. mile of agricultural area.			Milage per sq. mile of agricultural area.
1.	British India.	0·16	7.	Bihar.	0·124
2.	N. W. F. P.	0·264	8.	Bengal.	0.097
3.	Punjab.	0·093	9.	Bombay.	0·218
4.	U. P.	0·014	10.	Madras.	0·333
5.	Sind.	0·08	11	C. P.	0·122
6.	Orissa.	0·16	12.	Assam.	0·082

Madras has thus, the greatest milage of metalled roads per sq. mile of agricultural area.

It is a difficult question to decide, what increased milage the provinces should have, as this depends on several factors, which may not all be applicable, to any one province. We have, however, to decide this on some rational basis. The mass of figures given by the author have to be carefully checked, and analysed, before any general conclusions are drawn.

Mr. N. T. Gnanaprakasam [Madras].—The author of this very interesting and useful paper has invited discussion as to the possible means of securing a fully representative survey of the bullock-cart situation in the country.

I do not think there is any other method than that already advocated by the author, who has considered all possible ways.

If we refer to page 190 of the Paper, we find that three methods have been suggested for our consideration and I would say which I would consider best and why.

In the first two methods, we select about one in two hundred of villages in a District or Province and take a full count in those villages. If we do so, my feeling is that we do not get even one village to represent the different types and sizes of villages. Generally speaking, our villages can be classified mainly as [1] Wet or Delta [2] Dry or upland and [3] Tank or well irrigated, Forest etc. and each class can be sub-divided into at least five groups depending on the size [as determined by population]. Thus there will be at least 3 X 5 or 15 types of villages or towns and unless the count is taken for one, two or three villages of each group depending on the total number of villages in each group, we cannot secure anything like a representative survey.

Secondly, in the first two methods a full count is suggested in the selected villages. It is well nigh impossible to get all the carts in a village together at any one time. Neither do I consider it necessary because we are all aware of the monotonous similarity between the carts of one particular locality which are almost pattern moulded. In a District probably there may be three or four different kinds, varying only

in few dimensions. At any rate, it is so in the Madras Province. Hence much useful information cannot be elicited by a full count of carts, but on the other hand by surveying a greater number of villages more useful information on connected subjects can be got.

The third method has the advantage of giving us a representative or at least a more truly representative survey, provided villages representative of the fifteen or so different sub-groups are selected for survey. This selection can also be made to suit geographical or travelling conveniences, if possible.

To give figures, in Madras Province according to the first two methods a full account will have to be made in seven villages on an average, in each of the Districts. But you know that seven villages can by no means represent the different types and sizes of villages. But according to the third method about thirty villages may be surveyed taking only say 25 per cent. or even 10 per cent. count of the carts. This will give more representative information on all the aspects of the survey and will therefore be more satisfactory, and the extra money, time, and energy spent will be more than compensated by the better results which are bound to follow

The questionnaire is drawn up in great detail and is therefore very comprehensive but my only observation is that most of the information must be collected and kept ready for the enumerator before he actually visits the selected village. The nature of the information required is such that most of it can be furnished only from official sources *e. g.* the particulars under the 1st group *viz.*) crops etc. may be furnished by the officers of the Agricultural Department and those in groups III & IV by the officials of the Engineering, Agricultural and Revenue Departments Again some information, such as the unladen weight of cart under group III, cannot be obtained in the village off hand and must be got through some Engineering official. Hence my suggestion is that the questionnaire may be sent to some local officials in advance for furnishing the information which may be collected and verified by the enumerator.

The questionnaire is composed of very pertinent particulars on which information is sought and it would be prejudicial to the survey if we try to curtail it in any manner or to any extent.

Mr G. C Khanna (Punjab) :—I will deal with one point of Mr. Vesugar's interesting and thought-provoking paper in some detail. In paragraph 5, page 185, he has raised the following question :

"The only type of road that will stand up to the heavily loaded steel tyre is concrete, the really sensible wheel for any road transport purpose is the pneumatic tyred one. What should be one's objective then, the concrete road or the pneumatic tyre". In order to answer this question we will have to work out transport costs in relation to road maintenance charges. These have been worked out in detail below :—

If a ton of goods is moved on a road, the total cost of transport

consists of two parts i.e. (1) cost of transport by vehicle per mile per ton of goods carried say Cv (ii) Cost of maintenance of road per mile per ton of goods carried say, Cr.

The total of Cv and Cr should be kept minimum for efficient and cheap transport. For a metalled road Cv or cost of carriage of one ton of goods per mile is about two annas only. The cost of goods on an unmetalled road is about 25 per cent. higher *i. e.* is about 2½ annas per ton per mile.

Road Maintenance Costs.

It is a common practice to state the cost of maintenance of a road in rupees per mile per annum. This is not a correct method of describing the maintenance cost, as it does not bring into the picture, the traffic intensity on the road.

If A is the annual cost of a road in rupees, and T is traffic in tons per 24 hours, the cost of maintenance of road per ton of goods *i. e.* Cr is given by the formula.

$$Cr = \frac{A}{365\ T} \ldots\ldots\ldots(i)$$

The factor Cr determines the true economical value of a road to the community. The annual cost A is composed of three items (*i*) cost of maintenance per mile per annum; (*ii*) amortisation charges for the net capital cost invested in the construction of a road and (*iii*) interest on residual value of the road.

$$A\dagger = M + \frac{(F - R)r(1 + r)^n}{(1 + r)^n - 1} + Rr\ldots\ldots\ldots(ii)$$

Where M = Cost of maintenance of road per mile per annum.

F = Capital or finance invested in construction of road.

R = Residual or salvage value of road after n years of service.

n = Life of road in years.

r = Rate of interest on Re. 1/- per year.

Let us apply this* formula to the Punjab figures, and work out the annual cost.

M = Rs. 1,000/- (Cost of maintenance.)

F = Rs. 15,000/- (average) cost of metalling a road.

R = Rs. 7,000/- i. e. after a certain number of years the road will become uneven and will require scarifying and reconsolidation to bring it to proper shape. Rs. 7,000/- is the value of soling coat Stone, bajri, etc. that will be still available. It will cost about Rs. 8,000/- to reconsolidate and reshape the road.

* All the figures taken in this article are prewar.

† The 2nd term in this formula has been taken from Kempe's Year Book 1922 Edition page 5. The other two terms are obvious.

n = 20 years. If a road is given a subsequent coat of tar or bitumen, at intervals depending upon the traffic intensity, there is no need to reconsolidate it again. Some of the miles in the Punjab are 20 years old, and their surface is as good as new. Life of the road has been taken as 20 years to be on the safe side.

r = Rate of interest As money is cheap a rate of 3 per cent. per annum has been assumed. *Money for Haveli Irrigation Project has been raised by the Punjab Government at 3 per cent.

Substituting in (ii) we get:

A = Rs. 1,748

and $Cr = \dfrac{1{,}748 \times 192}{1{,}000 \times 365}$ for traffic of 1,000 tons per day.

= 0.9 pies or say 1 pie per ton mile.

This figure is only 4 per cent. of the cost of carriage by vehicle

Where the traffic intensity is less, the annual cost of road is reduced by giving subsequent coat of tar or bitumen after longer periods. The annual cost of these miles is therefore automatically reduced.

Roads on which traffic intensity is still lower, can be constructed to cheaper specifications. Soil-stabilized road can be made at a cost of Rs. 5,000/- and can be maintained at a cost of about Rs. 400/ per mile per annum. They can carry a traffic about 300-400 tons a day.

If we examine the figures of expenditure on roads in the United Provinces, where a large milage of concrete roads has been constructed, we will find that road maintenance costs in terms of ton-miles of goods carried are even lower than in the Punjab.

A concrete road costs about Rs 25,000/- to make; has a life of about 20 years and will have a residual value of about Rs. 12,000/-. If the road wears out after the period, it will be necessary to give a heavy coat of tar or bitumen. Its maintenance cost is about Rs 150 per mile per annum. Substituting these figures in formula (ii) we get,

A = Rs. 1383 or Say Rs. 1400

and Cr = 0.73 pies per ton mile for 1,000 tons of traffic.

A concrete road can take a traffic of about 2,000 tons to 3,000 tons per 24 hours without any detrimental effect. The value of Cr works out to about 0 4 pies where traffic is about 2,000 tons.

We thus find that extra cost of metalling a road is only 0.5 to 1.5 pies per ton-mile of goods carried, and the extra cost of carriage by vehicles on an unmetalled road is 6 pies per ton mile.

*Finances and Economics of Irrigation Projects by Kanwar Sain, I S E., Director, Central Designs, Haveli Project. Paper No 228, Punjab Engineering Congress.

The public thus incur, on its motor vehicles an expenditure which is 4 to 6 times that would be incurred on metalling a road.

If a toll is levied on new roads, it would be a commercial proposition for the Government. The amount of tax imposed on a vehicle should be less than the extra cost of running it on an unmetalled road. Let us examine whether roads are a success from financial aspect. Suppose there are two towns 32 miles apart, which are to be connected by a metalled road. The cost of metalling will be—

$$32 \times 15{,}000 = \text{Rs. } 480{,}000/\text{-}$$

The saving in cost of carriage on account of metalling the road will be 6 pies per ton-mile. Out of this sum of 6 pies let us assume that the Government levies a toll at the rate of 4 pies per ton-mile, leaving a balance of 2 pies for the encouragement of traffic. The gross earnings for the whole year with a traffic of 1,000 tons a day will be—

$$\frac{1000 \times 32 \times 4 \times 365}{192} = \text{Rs. } 2{,}43{,}000/\text{-}.$$

The annual cost of the road for 1,000 tons of traffic will be

$32 \times 1750 = \text{Rs. } 56{,}000/\text{-}$

The total gain will be Rs. 1,87,000/-.

Deducting overhead expenses, the net yield will be 30 per cent. over the amount invested.

Where the traffic intensity is less, the annual cost will also be less. The profits will be reduced undoubtedly, but there will always be a sufficient margin. For instance, if the traffic on the road is only 500 tons, the income will be 15 per cent. If the traffic is only 250 tons, and we construct a road with black top, the yield will be 4 per cent. If a low cost road i e. soil-stabilised road is constructed for such a low intensity of traffic, the income will be about 12 to 15 per cent.

The Irrigation Projects which yield 4 to 6 per cent. on the capital invested, after ten years of working, are considered "Productive"* and no Government ever hesitates to take these up.

Design of Road Crust.

Knowing the intensity of traffic that is likely to come on a road, it is now an easy matter to design the most economical type of road crust. The main consideration is, that value of *Cr* should be kept minimum. If *Cr* is assumed to be 1 pie per ton mile, the annual cost of different types of roads in terms of traffic using the road are given below :—

* Public Works Account Code Appendix Page 216.

Serial No.	Traffic intensity.	Annual cost of Road in Rs.	Proposed Road Crust.	Remarks.
1	Up to 100 tons	Rs. 200/-	Earth road.	For lower intensity of traffic, value of Cr will be more than 1 pie per ton mile.
2	100 to 300 tons	Rs. 200/- to Rs. 600/-	Stabilized soil road crust or brick track-ways.	do do do
3	300 to 700 tons	Rs 600/- to Rs. 1400/-	Metalled road treated with tar or bitumen	do do do
4	700 tons or over	Rs. 1400/- or more, depending upon traffic intensity.	Concrete road.	Value of *Cr* will be reduced for higher intensity of traffic.

Now I deal with the question of concrete roads versus pneumatic tyred carts.

In a general way it can be stated that where traffic intensity is low, it will be more economical to have carts with pneumatic tyres Where the traffic is heavy as in towns, it will be cheaper to have concrete roads

This generalisation can be proved by analysing costs of maintenance of a pneumatic tyred carts. We will have to make certain assumptions.

(1) The extra cost of maintaining a pneumatic tyred cart is about Rs. 30/- per annum.

[2] *Carrying capacity of the cart.* This varies from District to District. On an average 0.75 of a ton may be considered as the carrying capacity of a cart. "Casual observation in all parts of the country gives the impression that the general capacity of a cart averages less than 15 maunds"*. The load capacity of pneumatic tyred cart is not increased on account of pneumatic tyres, but on account of improved axles, and bearings. A solid tyred cart with ball bearings will be as efficient as a cart with pneumatic, tyres.

[3] *Distance travelled in one day.* A cart can travel fully loaded a distance of about 10 miles each day. On a particular day, it may travel more, but it is difficult to maintain an average more than this.

(4) A cart works for about 300 days in a year allowing break down, holidays to the cartman, etc.

The extra cost of carriage by pneumatic carts is $\frac{30\times 192}{10\times 300\times 3/4}=2.5$ pies per ton-mile.

*Para 4, Page 183 of the Proceedings.

Some Local bodies who have heavy traffic on their roads have either banned the use of solid tyred carts, or encourage the use of pneumatic tyred carts by remitting taxes, as they find that solid tyred carts are destructive to their metalled roads It has been shown above that concrete road is more economical than other types of metalled road where traffic intensity is about 700 tons, or more. Where the traffic intensity is less, the extra cost of making a concrete road over any other type of metalled road is about 0.3 to 0.5 tons per mile. This figure should not be confused with *Cr* which is the extra cost of making a metalled road over an unmetalled road.

Thus while extra cost of making a concrete road over other types of metalled road is 0·3 to 0.5 tons per mile where traffic is in the neighbourhood of 400 tons per day, and is nil where traffic intensity is 700 tons per day. The extra cost of running a pneumatic tyred cart is 2.5 pies per ton per mile.

It will be at once apparent that where traffic is heavy, pneumatic tyred carts afford an uneconomical solution to the problem It is cheaper to construct a concrete road, and allow all types of traffic.

Where traffic intensity is low, and a road cannot be maintained at a cost of 2.5 pies per ton mile, the pneumatic tyred cart will be more economical This cart has a considerable scope on village roads where traffic intensity is about 50 tons a day. A very considerable proportion of road milage of India carries this traffic.

Mr. M. A. Rangaswamy (Bihar):—The author of the paper has, in suggesting the questionnaire for an all-India survey of the bullock-carts, raised many interesting points in his paper.

Bullock-carts are the primary means of transport in India. The steel tyre wheel of the bullock-cart has a destructive action on the road surface (paras. 1 and 2 of the Paper, page 185). Every one will agree with the author for what is stated above.

What length of 70,000 miles (metalled) is affected by the carts and how many of 7 million carts are responsible for this ? What is the extent of use of the road by the bullock-cart ? Whether professional carts use them most, or the village carts carrying agricultural produce use them most ? What are the possibilities of converting the wheels of ordinary bullock-carts to pneumatic ones ? Is there a possibility of improving the wheels on the lines indicated by Mr Murrell?

To answer the questions raised above and to find out, if there is really a bullock-cart problem, the author suggests a bullock cart survey.

I think that the main problem is to have a traffic census, and a continuous record of the intensity of traffic both of bullock-carts and other fast moving vehicles should be maintained. If this is done, one can easily find out what particular areas would need special treatment in road surfaces and what areas would need ordinary surfacing. There have been a number of experiments made for the last 15 years to give us an indication as to what type of road surface would suit particular kind of traffic The I. R. C. in my opinion should lay down standards,

specifying certain kind of surfaces, for particular traffic intensities and segregation of bullock cart traffic and provision of cycleways etc. as the situation may demand

The cart survey, as it is suggested now, will no doubt help to gather a mass of information, on the type of bullock-cart now in existence, their period of work etc. but this information, at best, will serve to indicate the intensity of traffic at any particular time, at any particular place and possibly will help to find the information, needed, when the time comes for converting them to pneumatic tyred ones It may serve to show the extent to which the villages are served by the road, and this was stressed by Mr Kynnersley in his talk about the Pilot Road Schemes For future reconstruction of roads, the main points we have to take into consideration is what type of road construction should there be, where there is heavy concentration of bullock-cart and other fast moving vehicular traffic? Will segregation of the carts in these areas by cement concrete cycleways be desirable? What type of change should there be in the technique of construction to take the bullock cart traffic, in case, it is not possible to eradicate the use of the steel tyre, even by legislation or substitute the same by pneumatic tyre?

The proposed bullock cart survey, as is envisaged, will doubtless answer this point too As regards the possibilities of improvements of the wooden wheels, there is no doubt that great possibilities exist; you have seen the exhibits of wheel, outside the building designed and tested by Mr. Murrell and with persistent effort and encouragement, and more discussions in the congress, time is not far off when really cheap and efficient types of wheel could be evolved

Under item II carts, page 200, serials 37 and 38, it would be difficult to collect the information. Items 40 & 41 would answer the purpose, otherwise the questionnaire is exhaustive.

Mr. Ghose (Bihar).—We must do away with the offensive thing, the bullock-cart Most probably, after the war, they will naturally be done away with. All the pneumatic tyres and vehicles that you see are surely not going to be wasted After the war, someone like Tatas is going to buy up all these things and start a public carrier business These carriers using lorries and buses will automatically kill bullock-carts by bringing all produce etc from villages to markets, due to faster movement of transport.

It might be of interest to students of colleges to get these data which Mr. Vesugar has pointed out In the Indian Science Congress, there is such a membership, and they can submit their papers through a permanent member Some similar thing will help the Indian Roads Congress also

I would add another thing After the war, we will have more synthetic rubber, and I think in the Punjab and other places the cattle population is being decapitated About 15 cows are required now to give you milk for chota hazri. Same is the case with bullocks In China, they ate their bullocks, and there was no bullock cart problem They are likely to disappear, and so we must have the survey quickly

Rai Sahib Fateh Chand (U.P.)—My qualification for speaking on this Paper is that I was born in the village and brought up there, have served for 24 years in the villages I appreciate the interesting

figures that the author has collected. But these can be of little help, I am afraid, to the Road Engineer As I live in a village, I know what carts use the roads and what carts do not. In the aggregate, 94.4 per cent. of the carts live in villages because it is cheaper to maintain the bullock there. I must say that 90 per cent. of these do not use the roads at all The carts in the villages are of two types, one long and the other a small one which I might call a single seat cart. The latter is meant to take those people to bazar etc. The long cart is meant to bring produce from fields to the village. They do not take that produce to the towns. The banias etc come and collect these and take them to towns and cities in the 5 per cent. carts kept in the towns themselves So no idea can be formed by taking a census of the population or quantity of grains etc. which is produced. Then it depends on mills and similar industries If it is a sugar-cane area and there are mills, traffic on roads would be very heavy. This solution would be erroneous. My suggestion is that the survey should be of iron tyred and non-iron tyred carts. It is the number of iron-tyred carts which matters. Some 10 per cent. carts might use a road 30 times whereas other 90 per cent might not use the road at all except when they go to melas etc.

Another point is that we can do a lot by regulation of traffic. The damage done is great, but the percentage of carts which cause them is small. If we can manage that percentage, we will be able to solve the problem. We allow only light traffic on service roads. In the same way, we can regulate traffic on other roads. If you once put a cart on a partictlar route, it will follow it always. This remedy of regulating the traffic has been tried in several districts successfully, particularly with reference to light traffic.

Another point is pneumatic tyres. They are taking the place of iron tyres because they can carry much more at much less cost. It is also a fallacy that a pneumatic tyred cart cannot go where an iron tyred one can. Also these tyres wear out much less

Mr. A. S. Adke (Bombay).—I congratulate Mr. Vesugar for his very interesting paper. I was also born in a village One point which was very clear from the Paper was that statistics available in India did not provide the details necessary to enable the bullock-cart problems to be properly tackled. It is very difficult to make plans when we do not know exactly how much damage was being caused by bullock-carts. I, therefore, suggest that we should turn to para. 42, page 194 of Mr. Vesugar's Paper where he suggests that the Central Government should undertake a survey on the lines suggested in detail by him, and that this Congress should pass a suitable Resolution asking the Government of India to have this work put in hand.

Mr. Abdul Aziz (Punjab).—In para. 39, page 193, Mr. Vesugar has called for suggestions for simplifying the proposed questionnaire In my opinion, questions 5, 6, and 7 can be safely omitted. The information desired in question 5 is the acreage that can raise higher value crops with improved road facilities. The cultivators are not much influenced by road conditions as far as the growing of staple crops such as bajra, jowar, wheat, rice and cotton is concerned. It is the cultivation of perishable crops such as vegetables and fruits which can be extended when the facilities for the disposal of such produce are improved. The percentage acreage under these crops is very very small and its increase or decrease

depends primarily on irrigation conditions more than on road conditions.

Question No 6 is about acreage of additional land under each crop that can be brought under cultivation with improved road facilities Here again in order to bring additional land under cultivation it is the improvement in the irrigation conditions that is primarily desired

Question No 7 deals with the acreage that can be brought under crops but with improved well or gravity irrigation I am afraid that to collect the above information will be rather a confusing job for the enumerators and the results obtained will be guess work. At present (and I am speaking of the time after the War also) the financial difficulties in the way of any general improvement on a large scale, of the well irrigation in the well irrigated areas are practically insurmountable Similarly, it will probably be not of much help as far as the bullock-cart problem is concerned to hazard guesses on the possible development of areas for which there are Government Irrigation Schemes under consideration or in hand For the present the survey should best be of the present bullock-cart traffic conditions

Questions 47 and 49, page 201, will also be difficult for the enumerators or the cart owners and Lambardars to answer as the enumerators will have no data or definite observations to go by Now in the North West of the Punjab the bullock-carts are conspicuous by their absence in most parts of Attock, Mianwali, Jhelum, and Rawalpindi Districts. Villagers are not at all cart-minded, admittedly chiefly due to the peculiar topographical nature of their country. Here the donkey and camel have still undisputed sway. It will be very hard to say, and even if a guess is made, it will be of no statistical value, as to how many carts will appear if the village roads are improved; hence questions 47 and 49 are suggested to be omitted

Question No. 28 on page 199 is about the cost of a cart complete The figures of cost will be required for *plain carts* In the Colony Areas of Lyallpur and Sargodha Districts, I have seen ornamental carts owned by many zamindars costing as much as Rs 1,000/- although the plain cart would cost only about Rs 300/- The additional cost is incurred on embellishing the wood work by sticking on brass and copper plates stars etc.

The questionnaire is exhaustive and it is difficult to say whether any information can be omitted

Mr. Murrell (Bihar).—Mr. Vesugar has given us an exceedingly thoughtful paper. I must confess that my first impression was that the survey, if carried out, would result in collecting more information than one human mind could usefully employ.

As pointed out by the author, however, this matter of the bullock-cart concerns not only the road engineer, but all administrators of agricultural, veterinary, forest, mining, and other interests who have at heart the prevention of waste and the increase of efficiency.

What a pity we never had such a paper as this years ago In that case we would perhaps by now have definite information on which to design post-war road surfaces.

To have the best possible programme for post-war road work, we must provide good rather than expensive roads. A good road is that which serves the purpose with the least expense in construction and maintenance. An unnecessarily high and expensive type is a bad road.

Thus the Engineer should be able to say to the Administrator "I will see that you get good roads if you will obtain legislation to prevent undue wear and tear".

Before we can decide properly what wear and tear is undue, we should have the information made fully available by a survey of bullock-carts.

A paper like this need much more than discussion in the Indian Roads Congress. It needs following up. Here again I suggest the formation of a "Bullock-cart wheel Committee", or simply a "Bullock-cart Committee" of the Indian Roads Congress to take up this matter, with the least possible delay, with the Central Government, as also the question of large-scale experiments on the broad wooden tyre.

We must have that Bullock-cart Committee.

Mr. Lokanatha Mudaliar (Madras).—I shall start my comments by stating straight-away that I am a believer in the pneumatic tyres for the bullock cart used regularly and constantly on transport, as distinguished from the villager's cart used for joy rides and on occasional transport.

There is a fallacy in working out the cost of pneumatic tyred carts basing the calculation on taking the present costs. I wish to draw attention to the difference between ephemeral costs and permanent value. Costs change fast, with world events. If the Government decide, it ought to be possible to make tyres cheap enough to be practical. The economy in cattle and labour by the use of the pneumatic cart has been ignored. It was mentioned by a Food Adviser to Government that 800 carts of the present type would be required to haul the goods equivalent to one train. He added that the paucity of carts and the condition of the roads made transport of food-stuffs difficult.

If we had developed the pneumatic tyred carts, we would be saving 75 per cent. of this number, for producing food in the field. I had made 43 pneumatic tyred water carts in a District Board to supplant lorries for road watering purposes. These carts were later used on famine works and proved their immense use as also established the fact that these carts could be taken on all sorts of cart-tracks. Pneumatic tyred carts are used by Municipalities and Mill owners to great advantage.

I made a number of experiments on improved bearings of the steel tyred wheel but results were not encouraging and led to the conclusion that the pneumatic tyre is the *sine qua non* of improved bearings. So the pneumatic tyre is to be welcomed for the mechanical efficiency furnished by it.

In the survey the cost of maintenance of cart per ton should be given preference to and abridging the many other details about cost.

Mr. Ali Ahmed (Assam)—Mr. Vesugar deserves great credit for the useful facts and figures collected by him and compiled in his paper At the beginning of his paper he has, however, made a sweeping statement with which I cannot but differ He says "Every ton of produce moved in India, whatever its ultimate destination or method of transport must travel by cart for the first stage of its journey" I am sure he would not have made this statement if he had not postponed his proposed tour of Assam during the last month. In Assam particularly in the Surma Valley districts agricultural produce is carried either over the shoulder of the villager in a "*Bangi*" or in small boats by water routes before it reaches the weekly *hat* or market, from whence the traders remove it either by motor transport or by boat to large towns or Railway Station Some twenty-five years ago there were hardly any carts used in transport in the Surma Valley, the same applied to other districts of Eastern Bengal, the main reason being that water-borne transport is both cheap and easy and boats carry the greater part of the produce in its initial stages and a good deal of long-distance transport is also feasible by large boats and steamers In these areas, therefore, the bullock cart does not play the part which it does in other parts of India and this explains the reason why the number of bullock carts is comparatively small in Assam.

The statement made in para. 9, Page 186 of the paper that "the abnormally low cart population in N. W. F. P and Assam and to certain extent, Sind, can be explained by the nature of the terrain which either due to mountainous, desert or dense jungle conditions, militates against agricultural exploitation of the land", needs modification, for while this could apply to carts per square mile, it could hardly do so in regard to carts per 1000 persons as these ratios could not be affected by presence of mountains, deserts or dense jungle where there is no population. In the case of Assam it is mainly due to cheap water-borne transport that the number of carts is so small, and it is difficult to apportion the fraction of produce which is carried by carts

In paragraph 34, Page 192, Mr. Vesugar has stated that agricultural produce averages 5½ md. per head It can easily be inferred from this that damage to roads due to steel tyre bullock-carts occurs only where such traffic is concentrated near towns and railway stations The concentrated cart traffic near Lucknow where loaded carts come mostly inward is an example and here as we had seen during the Roads Congress at Lucknow, separate concrete strip had been provided at the sides, for bullock carts, whereas the main central carriageway was black-topped for the use of motor traffic As the problem of an All India Bullock-Cart Survey is of stupendous dimensions, I think it will be sufficient if atttention is concentrated to those areas only where bullock-cart traffic is extensive due to their industrial importance or location of trade centres This limited Survey can, I believe, go a long way in determining the dimensions of the problem which the road engineers have to face for devising ways and means to reduce the damage to road by bullock-carts

Mr. VESUGAR (Author) replying to the speakers and winding up the discussion said :—

Mr. Gnanaprakasam has made a definite suggestion that alternative 3 may be followed in collecting the statistics and has shown why this is the only possible method in Madras I wish he had not approved of the questionnaire so whole-heartedly and instead suggested drastic reduction.

Mr. Khanna makes a very interesting and economically sound suggestion, that in considering the movement of goods the incidence of the cost of haulage should be considered in conjunction with that of constructing and maintaining the "permanent way". His conclusions on the types of roads justified according to the intensity of traffic, are interesting. The development of this theme would need a paper to itself and I hope he will write one some day. The conclusions about concrete road surface versus rubber tyres is illuminating, and I have no doubt that these indicate the way towards a possible solution.

Mr. Rangaswami feels that what is required is a traffic survey and not a bullock-cart survey. I am afraid I cannot agree with this. A traffic census would have to be over the whole year and over 200,000 miles. I cannot see any means of doing this by either random or selective sampling. Further, a traffic survey may serve for the limited purpose of deciding on types of road crusts but the same result could be obtained through a cart survey with the additional advantage in the latter case that a complete picture of the problem of primary transport in India would be obtained at the same time. The results required by a traffic census should be possible, under the "self-help" scheme suggested at the end of the paper in paras. 52 and 53.

Mr. Ghosh mentioned that in China they ate their bullocks and thus there was no bullock cart problem. He hoped that transport will be quickly mechanized. I may mention that in Russia they killed off their horses for another reason with the result that, although millions of people died owing to the ensuing famine, an enormous number of tractors and combines came into being. I trust mechanization especially of transport will come into India soon as a process of evolution and without any suffering to the people. However so long as the bullock is required for drawing the plough, the bullock-cart will also remain as a means of primary transport. I am informed on very good authority that a reduction of the cattle population and concentration on improvement in breed both for draught and for milk would give a much stronger net animal power than at present. This is, however, outside the purview of the road engineer. Mr. Ghosh has also made a good suggestion about interesting college students in road matter. I would go further and suggest a drive to make each school and college adopt a particular road or group of roads not only for improving the physical aspect of communication but also for promoting road and traffic-mindedness.

Mr. Abdul Aziz has pointed out that with the improvement in transport conditions, it is not the acreage which increases but the character of crops. This is obvious and we may, therefore, omit from the questionnaire the numbers he desires to cut out.

It was pleasant to hear Mr Mudaliar speak from practical experience of working with pneumatic tyred carts. His experience about bearings is valuable He has come to the conclusion that it is a waste of time trying to improve wheel bearings and the correct solution lies in having pneumatic tyres with the type of hub that goes with this kind of wheel I have always suspected this and I am glad it has been substantiated from experience

Whether this suggested bullock-cart survey comes off or not, I hope we shall make the efforts to gather the information required for sound assessment of this problem that lies in our own power to collect As pointed out at the end of the paper to get these statistics does not entail any serious amount of extra work, I hope, therefore, that a beginning will be made at least with our trying to help ourselves.

PAPER No. K-1943.

CEMENT CONCRETING THE BOMBAY POONA ROAD

BY

W. H. E. GARROD, M. INST. C. E., M. R. SAN. I., I. S. E.,
Superintending Engineer, Public Works Department, Bombay.

Topographical Features of Country.

The country, through which the Bombay-Poona road passes, is extremely varied, consisting of the littoral of the Arabian Sea,—the comparatively low lying ground, 30-40 miles inland, called the Konkan ;—the buttress of the Western Ghats, rising abruptly in some parts for 3000 feet and reaching a maximum height of 5400 feet above mean sea-level ;—and the Deccan plateau, starting at 2000 feet above the sea at the passes through the Ghats, and extending eastwards with a flat but even slope down towards the Bay of Bengal (vide plates 1 and 2).

The average rainfall within the area is also extremely varied. Between October and May inclusive, it is negligible, but during the south west monsoon, the sea coast on an average receives 80 inches, which increases rapidly inland over the Konkan up to 250 inches on the Ghats, and then drops even more rapidly to 30 inches within the next 30 miles to the vicinity of Poona.

From the sea, over the Konkan and the Ghats, due to this heavy rainfall, there is extensive and, in places, thick jungle, but it is "low" because the intensity of the rain during the 4 months of the south west monsoon washes the soil from the hill sides and so stunts the growth of the trees.

As the rainfall exceeds 50 inches in the monsoon, from the sea to some distance east of the Ghats, rice is the predominant crop, wherever cultivable soil is available.

The tops of the hills of the Ghats accommodate the forts of the Maratha warrior, Shivaji, of the 17th century, and, considering their age, these forts are in a remarkable state of preservation.

Historical.

The route joining the commercial capital of the Province of Bombay, with Poona—the old Maratha Capital, and the monsoon seat of the Government of the Province—has not always followed its present alignment. From records, it appears that at least up to the end of the 18th century, travellers and merchandise crossed Bombay harbour to Panvel Bunder, 12 miles to the east, and then proceeded up to and over the Western Ghats on foot, in *doolie* or on horse back, goods being carried by pack animal (vide plate 1). There exists to-day in Poona, an old milestone "To Panvel Bunder, 70 miles",—a relic of the past.

At the beginning of the 19th century, roads were constructed from Bombay to Thana, on to Kalyan and thence to Panvel, circumventing Bombay harbour, the crossing of which in the monsoon was far from pleasant. This new alignment however necessitated the negotiation of 2 creeks by boat, and was very circuitous.

About the middle of the 19th century, an iron bridge was erected across the creek at the north end of Bombay harbour and the present

alignment from Bombay via Thana, Panvel, and Bhor Ghat, to Poona (113 miles long), came into vogue.

The road runs practically at sea-level up to Thana and, with undulations through the Konkan, is 300 feet higher at the foot of the Bhor Ghat, 66 miles from Bombay. It then rises 1500 feet in 4 miles (milestone 70), reaching 2000 feet above mean sea-level at Lonavla (milestone 74), and dropping 200 feet in the remaining 39 miles to Poona, (vide plate 2). Buddhist caves both above and below the Ghat make it probable that this pass was a highway of traffic between B. C. 100 and A. D. 600. The existing alignment of the Ghat has, for a short length, a gradient of 1 in 7.6, the ruling gradient being 1 in 10 and average 1 in 15 2 The hair pin bends are extremely sharp and combined with the gradient possibly present as severe a test as anywhere in India on a road of similar importance. Apropos of wheeled traffic in 1830, hardly a single cart was met with on the road. The only local cart wheels were discs of stone, and carts were large lumbering contrivances, which remained as hairlooms in families for generations. Droves of pack bullocks held possession everywhere.

Improvement in Modern Times.

The first proposals to improve the road surface in modern times were considered shortly after the last war, when, according to all accounts, its condition was far from satisfactory These proposals concerned only the reconditioning of the water bound macadam, and this was subsequently carried out Some miles which run through rice fields, level with the road surface, and consequently which suffer from sub-soil water at ground level in the monsoon, were treated with 2½ premixed asphalt macadam with seal coat after drainage had been improved and Irish bridges or dips eliminated. This with subsequent repairs has stood well, although with the adverse condition of intense rainfall combined with the prevalent heavy military traffic, the length requires constant attention.

The worst curves on the Bhor Ghat then received treatment, and were eased as far as was possible. Easing of the gradient near the top by utilising the abandoned G.I.P. Railway tunnels was considered, but as the tunnels were long and in curve, and the lighting arrangements costly, this proposal was given up.

Concreting.

It seems that the best form of construction to effectively withstand the heavily laden Deccan bullock cart with its narrow convex iron tyre is cement concrete Tar and asphalt, especially in the hot weather are apt to rut, and in May, which incidentally is the hottest time of the year in the Deccan, it is almost possible to see the narrow cart wheels "digging in". Such a cart carries something over half a ton

Concreting actually started in 1938 before war broke out, and the major part of the work has now been completed.

It is the ultimate aim to provide a continuous concrete road from Bombay to Poona, but to expedite improvement to the surface, and, due to the prevailing shortage of cement, asphalt and tar have been laid temporarily in some lengths.

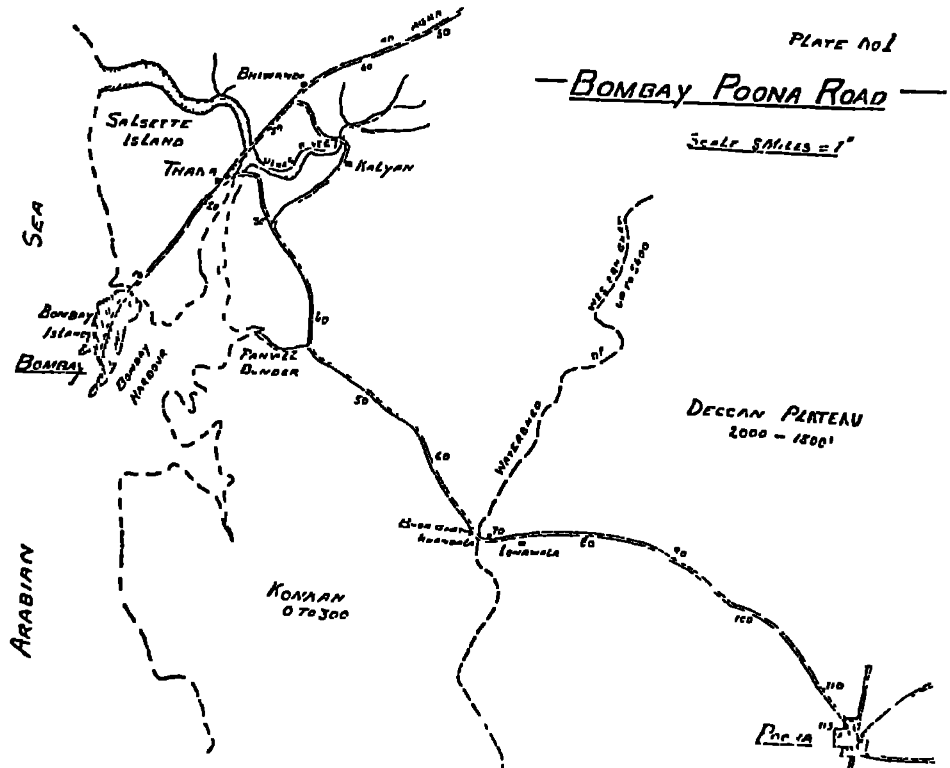
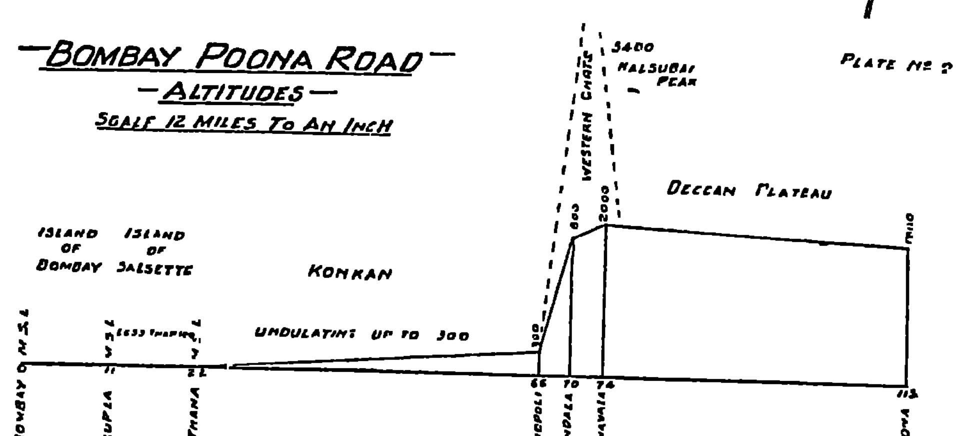


PLATE NO 1
BOMBAY POONA ROAD
SCALE 8 MILES = 1"
Bhiwandi
Salsette Island
Thana
Kalyan
SEA
ARABIAN
Bombay Island
Bombay
Bombay Harbour
Panwel Bunder
Deccan Plateau
2000 – 1800'
Konkan
0 to 300
Lonavala
Poona


BOMBAY POONA ROAD
ALTITUDES
SCALE 12 MILES TO AN INCH
PLATE NO 2
3400
KALSUBAI PEAK
WESTERN GHATS
DECCAN PLATEAU
ISLAND OF BOMBAY
ISLAND OF SALSETTE
KONKAN
UNDULATING UP TO 300
BOMBAY
KURLA
THANA
KHOPOLI
KHANDALA
LONAVALA
POONA
66
70
74
113
800
2000
1810

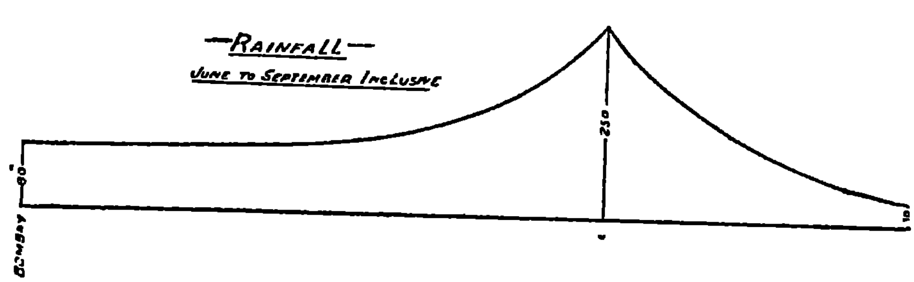

RAINFALL
JUNE TO SEPTEMBER INCLUSIVE
80
250
BOMBAY

PLATE NO 3

BOMBAY POONA ROAD

DOWEL & ANCHOR PINS ON BHOR GHAT

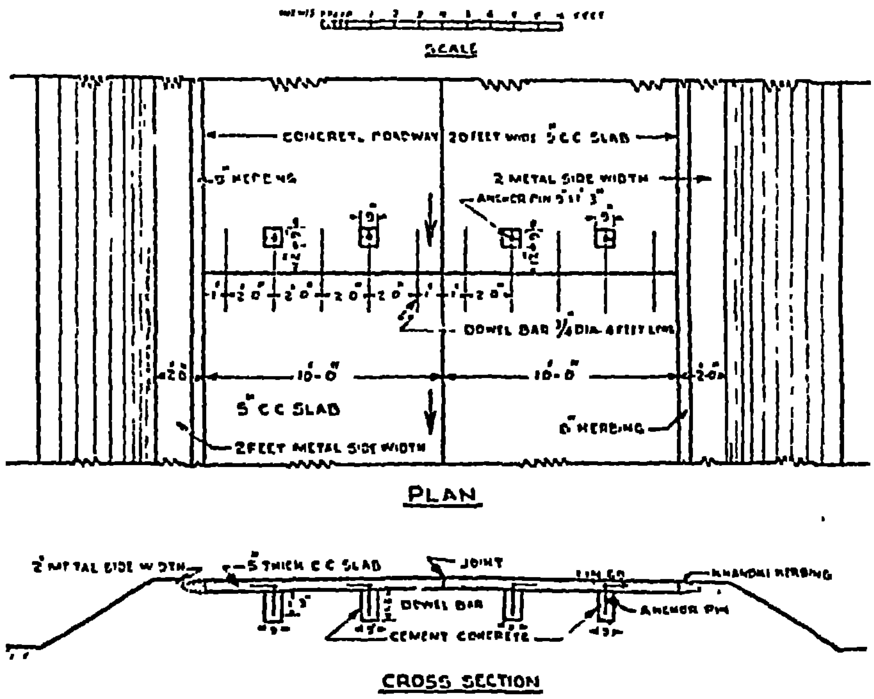
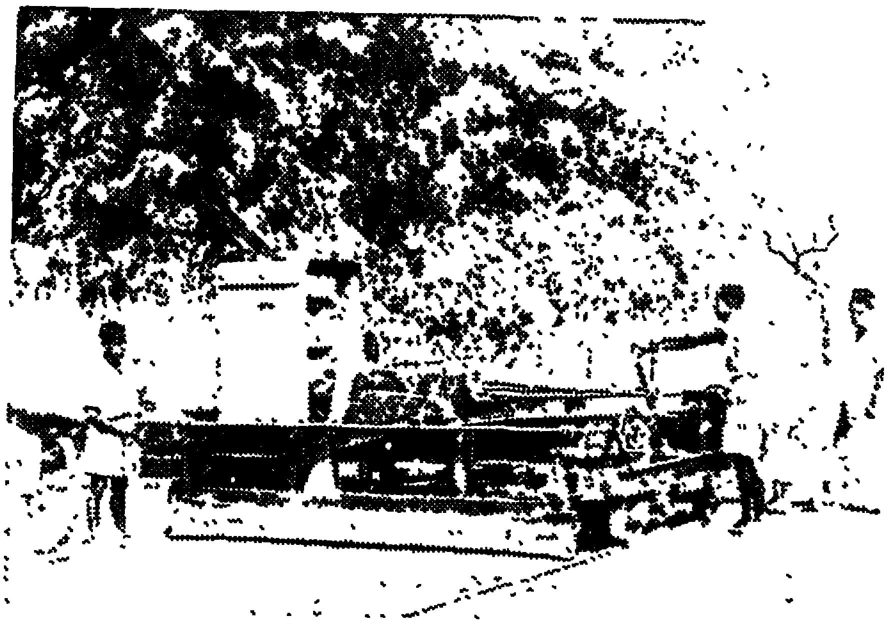


PLATE NO 4

BOMBAY-POONA ROAD

RATE ABSTRACT FOR CONCRETING 5" SLAB

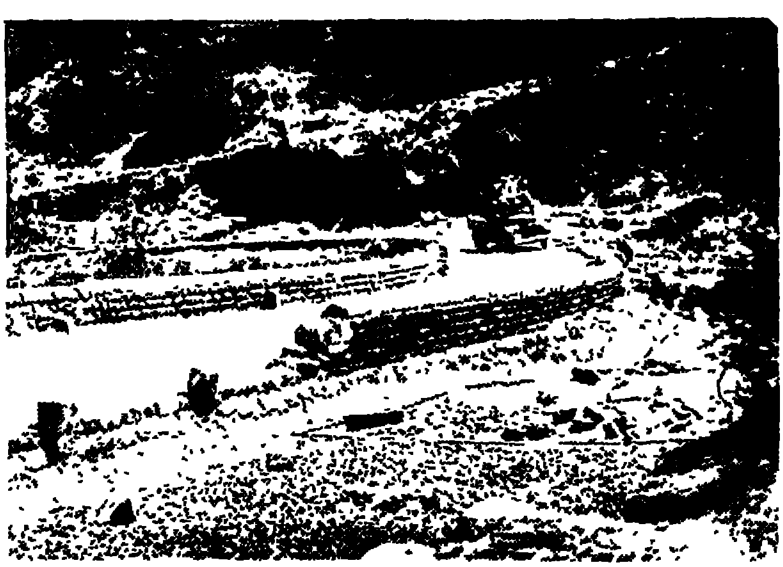
DESCRIPTION OF ITEMS		[illegible]				[illegible]				[illegible]			
		Quantity	Rate Rs	Unit	Amount Rs	Quantity	Rate Rs	Unit	Amount Rs	Quantity	Rate Rs	Unit	Amount Rs
MATERIALS													
METAL 1½" TO ¾"	CU FT	25	8	100 CU FT	2	25	7 9	100 CU FT	1 15	50	10	100 CU FT	5
METAL ¾" TO ¼"	CU FT	12 5	16	100 CU FT	2	12 5	13-10	100 CU FT	2 8	16	18	100 CU FT	2 14
SAND	CU FT	12 5	8	100 CU FT	1 8	27 5	6 15	100 CU FT	1-9	25	28	100 CU FT	7
CEMENT	BAGS	7 1	9 8	TON	13 8	8 2	35 4	TON	14 1	8 4	45	TON	12-5
DOWEL BARS	LBS								0 10	8 4	18	CWT	1 6
INSULATION PAPER	ROLLS					0.15	8 8	ROLL	0-14	0.13	17	ROLLS	2-4
EXPANSION JOINTS	NOS				1-4				0 8				1 0
TOTAL FOR MATERIALS					23 4				22 1				36-[illegible]
LABOUR													
MIXING LAYING TAMPING FINISHING INCLUDING FIXING FORMS & JOINTS	100 SQ FEET				3 8				2 10				4
CURING	100 SQ FEET				1				1-9				3-[illegible]
TOTAL LABOUR					4 8				4 3				7 10
CONTINGENCIES					1								1
TOOLS & PLANT					0-4				0 4				0.9
GRAND TOTAL 100 SQ FEET					26				26 8				46



Tamping Machine. Front View Photo 2.

Rear View Photo 3.

Laying the insulation Paper and placing concrete. Photo 1.



Bhorghat-Bombay Poona road showing narrow drain and sharp curve Photo 6

The Sub Grade.

The old surface of the road consisted of water bound macadam of dark blue Deccan Trap, some 4 inches to 6 inches in thickness, on top of muram. As this was uneven, it was reconditioned with 6 inches of new metal of 3 inch guage, with an alteration in camber from 1 in 30 to 1 in 60. To ensure complete consolidation, traffic was allowed over the new surface for a month, before concrete was laid.

Subsequently due to the shortage of power rollers, which had been requisitioned by the Government of India for aerodromes and other purposes, and to ensure a more evenly consolidated sub grade, the old surface was covered and brought up to the new camber with a weak mix of 1:3:6 cement concrete, laid simultaneously with the slab. This with the slab above was known as *"bonded concrete"*.

The Wearing Surface or Slab.

The slab is of 5 inches uniform thickness, 20 feet wide, of 1:2:4 cement concrete, laid in two strips 10 feet wide with a central longitudinal joint The transverse joints are at 35 feet centres. In the beginning, khandki kerbing of 6 inches width was provided with a $1\frac{1}{2}$ feet metalled width beyond, but this kerbing was omitted later on as it appeared to be serving no useful purpose (vide plate 3.)

The aggregate utilised was of crushed Deccan Trap stone and *Mumbra* sand (from near Thana) in the proportion given in the Rate Abstract attached (plate 4). The slab was estimated to cost Rs. 26/- per 100 square feet (plate 4). It was actually executed for Rs. 26-8-0 before war broke out, but the current rate is Rs. 46/- per 100 square feet, and in the case of very urgent works of military importance, this was as much as Rs 52-8-0 per 100 square feet at the height of military expenditure round Poona in 1942.

Forms and Mixing.

When the sub-grade was ready to receive the concrete, longitudinal timber beams or steel channels, 5 inches high, were placed 10 feet apart, and kept in position with spikes driven into the sub-grade (vide photo 1). The insulation paper was then unrolled covering the full 10 feet width, and all timber or steel, which would make contact with the concrete was oiled. The mix was kept as dry as possible, $4\frac{1}{2}$ to $5\frac{1}{2}$ gallons of water per bag of cement being used, according to the amount of moisture in the aggregate.

Mixing was done in Millar's mechanical mixers (capacity 10·7 cubic feet), utilising one bag of cement for each mix. The time allowed for mixing each batch was 2 minutes Measurement of cement was by weight —actually by sealed bag.

The initial mixes in each shift were made richer in cement, as part tends to adhere to the inside of the mixer until the latter is well coated. A mixer turned out about 100 cubic feet per hour.

In laying bonded concrete, no insulation paper was used The shuttering was first laid down the centre of the road for a day's work, true to line and level The side shuttering was then fixed at 10 feet distance and at a crossfall of 1 in 60.

Before placing the weak concrete, the water bound macadam surface was thoroughly cleaned with wire brushes and well watered The first and last foot length of each slab was given the standard 1·2 4 mix for the whole depth The weak mix was well tamped with rammers to fill in all inequalities and was finished off under the side shuttering in a 1 to 1 slope. The placing of the 1:2.4 mix followed about 10 feet behind the weak mix, to ensure a homogeneous mass.

Tamping.

This was effected partially by hand and partially by machine. With a heavy double handled timber tamper, one bay 35 feet long by 10 feet width was covered in an hour and 24 minutes, but with the mechanical tamper, the same area, if supplied by 4 mixers, could be covered in 24 minutes.

The mechanical tamper (vide photos 2 and 3) was supplied by the Concrete Association of India, and loaned by them free of charge. It costs Rs. 15,000/-. Their representative was present during the whole period of the concreting and the P.W.D. Establishment had instructions to comply with all his demands.

The machine consists of:—

(a) an oscillating screed,

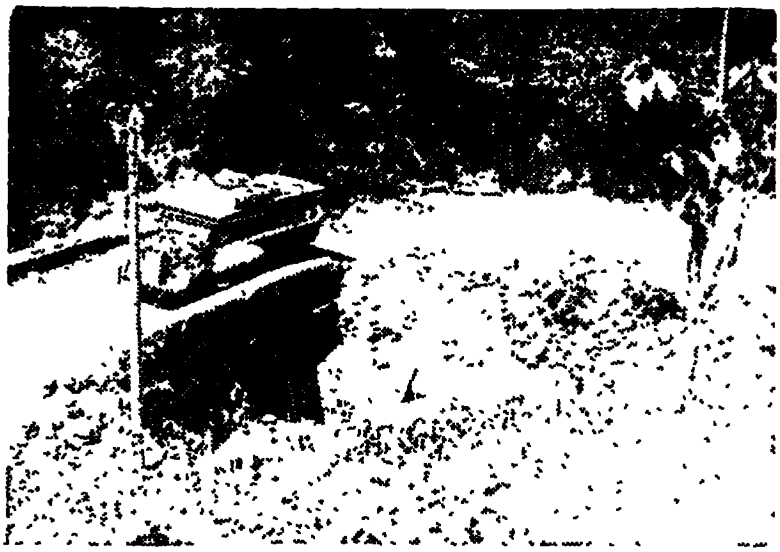
(b) a vibrating beam 9 feet 10 inches long and approximately 2 feet wide, the bottom of which is shaped in cross section like a very flat V,

(c) a finishing screed.

The machine travels over the freshly laid concrete, with screed (a) adjusted to half an inch above the finished level. The vibrating beam follows at the finished level and the finishing screed is kept clear. It reverses with (a) and (c) raised and (b) in position, and then goes forward with (b) and (c) in operation, (c) smoothing off the surface and removing any excessive cream. A bass broom was then drawn lightly over the surface transversely (vide photo 2).

Jointing Material.

The jointing material used in the transverse joints was a pre-moulded filler ½ inch thick consisting of 2 layers of felt with tar in between, whilst hand tamping was in vogue. As the machine broke down the resistance of any flexible material, the transverse joints were subsequently formed by a steel plate 4 inches high i.e. about 1 inch below the finished surface, tapered in section, (thicker at the top than at the bottom) to facilitate extraction, and with a hole at the top at each end for the insertion of wire to effect withdrawal. The plate was removed 15 to 20 minutes after tamping was finished and the



Bhorghat – Widening of masonry works in Progress (Photo 5)

Roughened surface on Bhorghat Photo 4.

joint stuffed with paper to keep out dirt. The joint was subsequently filled in with a mastic consisting of 60 per cent Mexphalte, 38 per cent fine sand and 2 per cent cement. The longitudinal joint was a butt joint simply tarred.

Dowel Bars.

5 dowel bars, 4 feet long and $\frac{3}{4}$ inch diameter were placed at 2 foot centres 3 inches below the top of the slab to connect the slabs longitudinally and equalise the load (vide plate 3). Subsequently due to the difficulty in obtaining steel, these were omitted and so far the omission does not appear to have been detrimental to any great extent but it is early to give a definite decision.

On the Bhor Ghat with its steep grade, special measures had to be taken for anchoring the slab to prevent "creeping", and also for roughening the surface to allow bullocks to maintain their hold.

Anchorages consisted of $\frac{3}{4}$ inch bars, 2 feet long, bent at right angles at 9 inches from one end, the 15 inches being embedded vertically in concrete, 9 inches square in plan and 2 feet deep, below the slab, the horizontal 9 inches of the bar being incorporated in the slab and tied to the continuous dowel. 2 of these bars were inserted at the lower end of each slab in addition to the normal dowels (vide plate 3).

Roughening the Surface on the Bhor Ghat.

Immediately after the tamping had finished, the smaller mix was carefully removed from the surface by means of wire brushes, leaving a mosaic of large metal, which has so far effectively provided a grip. The larger metal was left about 1/8 inch proud (vide photo No.5).

Drainage.

On the principle that a rupee spent on drainage is worth two rupees to a road surface, the roadside drains, especially in the areas of heavy rainfall, have been deepened and graded.

The masonry works have also been widened and reconstructed to bring them up to modern loading.

Difficulties in Construction.

The major part of the work has been carried out since the outbreak of war, and one of the greatest difficulties to smooth progress has been the passage of long military convoys through the traffic controls. During the passing of wide lorries, work had to stop completely, as diversions through the fields were very seldom possible.

Other difficulties have cropped up in the supply of cement and petrol. Also, due to the failure of the late rains in 1941, water became very scarce in the hot weather of 1942 and had to be carted long distances for curing. Colas-cure has been utilised in some cases under such conditions. In addition very extensive military works were in progress in the area, through which the road passed, and the rates for labour went up more than 100 per

cent. Labour was literally press-ganged during the night and was in consequence difficult to retain.

Cracks and Opening Joints.

The concrete has shown no signs of disintegration, even under the caterpillar wheels of heavy tanks, but the longitudinal joints have in places opened slightly, and some cracks have appeared. The opening of the joints is usually on embankment—either on an old embankment composed of poor material, or on new embankment, that has not thoroughly consolidated. Also where embankments are subject to a large difference of level of water in the hot and monsoon seasons, the swelling of the embankment in the wet weather drags the two widths of the slab apart and the contraction in the subsequent dry season does not take them together again, producing a longitudinal joint, which increases annually. Under such circumstances it would seem advisable to eliminate the longitudinal joint, if at all possible, and reinforce the full width with fabric.

The cracks are due to exceptionally heavy loads on uneven support, a point in favour of "bonded concrete." The 4 edges of a slab were of course rounded off about 1 inch diameter and the jointing ironed down.

Appreciation.

I should like to acknowledge the information extracted from a note by Major R A. Fitzherbert, I S.E, on "Modernisation of the Bhor Ghat", which was to have been published in the journal "Indian Roads", (unfortunately suspended for the duration of the war). Major Fitzherbert, before he retired from the Indian Service of Engineers of the Bombay Presidency in November 1941, was in charge of the work, and was, of course, wellknown at the Indian Roads Congress.

Tuesday, October 5th, 1943.

Mr. Mahabir Prasad (Chairman) :—I call upon Mr. W H.E. Garrod to introduce his paper " Cement Concreting the Bombay-Poona Road ".

The above paper was taken as read.

Discussion.

Mr. Garrod (Author) :—A small printing error which is not very obvious should be pointed out. On page 209, in the third para, under " Dowel Bars ", the word should be " contiguous " and not " continuous ".

At the top of the same page are given the proportions of the jointing mastic used with the mechanical tamper. The proportions finally adopted were 33 per cent. R2 mexphalte, 60 per cent. fine sand, 5 per cent. cement, and 2 per cent. finely chopped hemp.

Turning back to the top of page 207 in the 1st paragraph under sub-grade, the statement made in the 2nd sentence that the old surface was reconditioned with 6 in. of new metal of 3 in. gauge is too comprehensive This took place only in those lengths where foundations were bad, generally due to paddy fields on both sides on a level with the road surface. Otherwise reconditioning with 2 in. thickness of 1½ in. metal was effected ; where bonded concrete was used to obtain the change in camber, the old surface was not disturbed.

Regarding horizontal curves, these were realigned to lemniscates, superelevation was limited to a 1 in 12 side slope. The parabolic camber of 1 in 60 on the outer side of each bend was eliminated in the 50 ft. before the start of the curve. The surface on all curves was widened, where the radius justified it, and anticlines along the road were eased by excavation to improve visibility.

The normal progress of work with the mechanical tamper, supplied by four mixers, was on the average one mile of 20 ft. width per month.

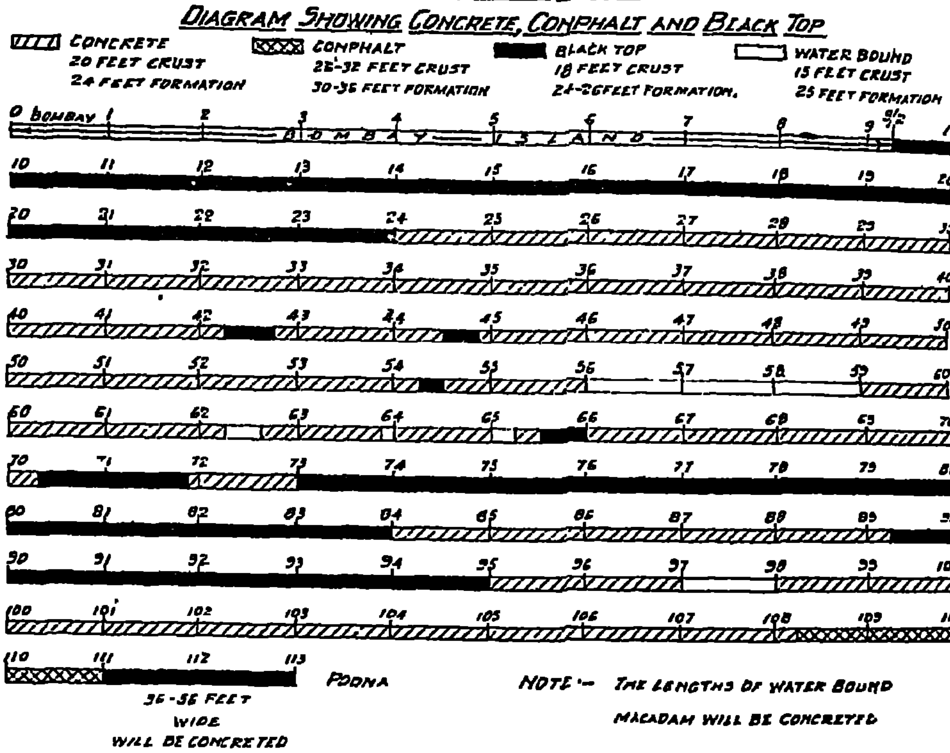
The traffic census which showed up to 1,000 tons per day in peace time has risen to 3,500 tons on some days since the outbreak of war.

The chart on page 210 (b) indicating the lengths of black top, concrete, and *conphalt* shows that the proportion of black top to concrete is at present about 1 to 2.

The total cost of improvement to the whole road, excluding the first 9¼ miles, which lie on the island of Bombay, and which do not come under the P.W.D. will be in the neighbourhood of 55 lakhs of rupees Of this, 14 lakhs represent black top, 40 lakhs concrete, and 1 lakh *conphalt*. Of the 40 lakhs under concrete, 3 lakhs were spent on the 4 miles of the Bhor Ghat.

BOMBAY POONA ROAD. PLATE 5

DIAGRAM SHOWING CONCRETE, CONPHALT AND BLACK TOP



Mr. K. S. Raghavachary (Simla):—We must be thankful to Mr. Garrod for having given us an interesting paper on the concreting of Bombay-Poona Road, a distance of 113 miles When fully completed, this would be the longest stretch of concrete road in India

This subject of concrete roads has of late been assuming much importance in India and the United Provinces have taken the lead and developed thin cement concrete roads to suit light traffic. In their opinion, these concrete slabs are considered to be more economical in the long run than black top roads, or even water-bound macadam.

The value of the paper would have been very much enhanced if more details about the methods of design, construction, and the execution had been given It is requested that the information on the following points may, if possible, be given:—

(1) The choice of cement concrete over other types ,

(2) The design of the thickness of the concrete for the existing or anticipated traffic on the road ;

(3) The formula recommended by Bruce is :—

$d = \sqrt{\frac{3 \cdot w}{s}}$ where d = Required edge thickness in inches.
w = Maximum wheel load in pounds.
s = Allowable flexural unit stress in concrete pavement in lbs. per sq. foot.

(4) The special considerations for using a uniform thickness of 5 in. slabs as against the thickened edges ;

(5) It is usual to adopt construction joints at a distance of 30 to 33 ft. and introduce an expansion joint only at about 100 ft. intervals. In the present case, expansion joints have been used at every 35 ft. This would increase the number of bumps on the road ;

(6) Details of superelevation and the nature of the vertical and horizontal curves adopted ;

(7) The special reasons for adopting a mix of 1:2.62 : 5.28 ; whether this was done on a rational basis, or to provide for the bulking of sand, or on a mechanical analysis ;

(8) The change in the proportion of mixing different sizes of aggregates in the years 1938-39 and 1942 from the estimated ratio of 1:2. It would be interesting to know whether this alteration was based on any compression test or maximum density ;

(9) The thickness adopted at the centre of the road for the bonded concrete for the weaker mix (1 : 3 : 6) ; the comparative cost of the weaker mix and the water-bound macadam with 6 in. thickness of new metal.

(10) Whether the special anchorages provided in the Ghat portions were only at the end of the slabs or distributed throughout the length.

Mr. J. T. Mehta (Bhavnagar) :—It was pointed out at the Second Indian Roads Congress by Lt.-Colonel W. De H. Haig, that if traffic is more than a painted road will stand for three years without repainting, then the only economical surface is concrete. The annual road cost of one inch asphalt macadam carpet is more than that of 4 inches cement concrete if the latter lasts for 14 years. As cement concrete is the only surface that would withstand bullock cart traffic, its use is becoming more prevalent.

It becomes imperative that instead of wasting money on thicker cement concrete roads we should arrive at some definite conclusion which would show us what thickness to adopt under different circumstances. Mr. Jagdish Prasad and Sir Kenneth Mitchell have shown at the 4th Indian Roads Congress in their Paper No. E that for a wheel load of two tons, five inches uniform thickness of cement concrete Road Slab would be required when the safe bearing capacity of soil is taken as 32 lbs. per sq. inch i.e. when c in sheet's formula is taken as 0.84.

In the United Provinces, thickness of less than 4 inches have stood well on old macadam crust. In the "Indian Concrete Journal" of May 1938 has appeared a paper from "Surveyor" written by H.E. Brooke-Badley who gives the formula for the design of concrete roads as :—

$$\text{Pneumatic tyres } S = 1.92 \text{ W.C.} \div d^2$$
$$\text{Solid tyres } S = 2.4 \text{ W.C.} \div d^2$$

whereas Sir Kenneth Mitchell gives the latter formula as that for pneumatic tyres.

The coefficient for sub-grade support to be adopted for well consolidated macadam crust of sufficient thickness should be investigated This will result in reduced thickness of the road slab resulting in reduced cost. In this particular instance six inches of new metal has been added to the already old water bound macadam road and then 5 inches of slab has been put on it. I think either the slab could have been less or else if 5 inches thickness of slab was to be put, only necessary re-sectioning of the old W.B macadam would have been sufficient. At least some trial length ought to have been put on these lines and results made known at a future session of the Indian Roads Congress.

There is just one point more. It has been stated that it is found that longitudinal joints are opening out. I think it is due to the omission of kerbs. It is not stated whether the two feet berms of water-bound macadam on either side were rolled by means of power roller or not, but had there been kerbs and had the berms been properly rolled after allowing 28 days for the setting of cement concrete road slab, by means of say six ton Tandem Type Roller, there would have been less likelihood of the longitudinal, joints opening out because the side ditches are already made deep and dressed to proper grade, thus carrying off the water from the bank immediately

Mr. T.R S. Kynnersley (Bombay) :—With reference to the desirability of doing away with longitudinal joints especially over black cotton soil it is pointed out that on many parts of this road it was very difficult to make deviations owing to the fact that the road is on a high bank surrounded by rice fields ; therefore half the road must be kept open for traffic so making a longitudinal joint indispensable.

If reinforcing steel had been available it should have been used on certain bad sections.

Bonded concrete is of two kinds, that in which a thin layer of reinforced concrete pavement is laid over a thoroughly compacted road and bonded thereto and that in which a weak mix of concrete is placed on the old road to bring the road to the proper level and camber for the surface mix This latter method has been used with great success on this road and unless considerable time is allowed to elapse and traffic allowed to pass over new water-bound macadam, this method is preferable.

Mr. Mohammed Farhatullah Hyderabad, (Deccan) :—

The Sub-Grade

In the treatment of the sub-grade it has been mentioned that it was reconditioned with 6 in. of new metal of 3 in. gauge and to ensure complete consolidation traffic was allowed over the new surface for a month before concrete was laid.

As I understand the sub-grade, is provided under cement concrete pavement to act as a supporting base and in order that the cement concrete slab laid over it remains undisturbed when subjected to traffic, the sub-grade is expected to be of uniform character This uniformity is conferred on it by its compactness which in its turn depends on :—

(1) Its interlocked condition so far as its own composition goes,

(2) Its mode of accommodation into the surrounding material.

The passage of traffic over the sub-grade for a period of one month would no doubt have produced some effect as regards the feature No. 2, described above in that it would have caused its equable spreading, but it is doubtful if it would have driven home the new material into close juxtaposition with the old sub-grade and also if it would have been able to bring about the feature No. 1.

I think that in this respect the gauge of the metal adopted deserves due consideration and hence I am of opinion that a mixed aggregate made up of sizes ranging say from 1½ in to 2½ in and placed in the order of these different sizes, the biggest aggregate forming the lowest layer, would have proved more suitable for the purpose.

The cement concrete layer of mix 1: 3: 6 placed over the sub-grade will admittedly tend to minimise the surface unevenness of the sub-grade but it cannot go to radically cure the defect of looseness of the sub-grade.

Very steep grades mark the alignment of the road along the Bhor Ghat and it is taken for granted that the physical features of the country rendered them unavoidable.

The steepness has necessitated special measures to anchor the slab to prevent creeping, but it is to be observed that the sub-grade which consists of dry metal of 3 in. gauge has been left as it is without the provision of the cross retaining walls at suitable intervals. These would have kept the sub-grade in a well-packed compact condition on such precipitous slopes as 1 in 7.60.

Rai Sahib S.K. Ghosh (Bihar) enquired if any truncated conical coloured blocks were placed in the concrete to measure the wear and suggested the adoption of the same for future works in order to have a record of the wear.

Mr. G.B. Vaswani (Karachi) :—I have constructed two roads. On one of the roads, I have put in insulated paper. I find after six years that there is not a single crack in the road, although the road leads to a railway shed, and we have got very heavy traffic over the road. The reason for absence of cracks may be the introduction of the insulated paper. In the last session of the Congress, Mr. Walker gave us a paper on thin slabs of concrete, in which he advocated the sub-grade to be bound with cement concrete. That gave better results.

Another point is that the joints are very small, quarter of an inch or so. I introduced socony No. 6 mixed with sand and I find that gave better results, because it penetrates and at the same time mixes up without heating. It also gives better results to paint the pavements as well as the fillings with socony No. 6 mixed with sand.

As regards expansion joints, there is some trouble, but my experience is that if you lay cement concrete in alternate bays, there will be not much expansion of joints.

Mr. T. Loknatha Mudaliar (Madras) enquired if this rigid type of pavement viz cement concrete was laid on steel bridges on the road. He was of opinion that due to vibrations in steel bridges this rigid type of cement concrete pavement would crack.

Mr J. Vesugar (Simla) enquired if the reasons for the cracks are being investigated.

Mr. Mahabir Prasad (Chairman).—On page 209, it is said that the surface was roughened in order to provide a grip. I would like to know whether this has been found to be useful in practice. I would also like to know how the joints have behaved. In U.P., the tendency of some of the joints is to fall off, the reason probably being that the cambre does not get joined properly Regarding dowels, I should like to have some information as to whether these dowels have been of any help, especially as the paper itself says that their omission has so far had no detrimental effect to any great extent.

Mr. Garrod (Author) :—We are very short of rollers, and we have come to the conclusion that we would get better job by using the old face, as we have got on this road a very good thickness of old metal.

The question of steel bridges was raised. As a matter of fact we have not had to deal with any steel bridges. But in such a case, I think, bitumen was the solution. Mr. Vesugar enquired whether the reasons for the cracks in the surface were being investigated This is being done, but I think it is too early to give any results These cracks, as they develop, are being watched, and the reasons for them, as far as possible, are being obtained. I hope a note on that will be made available for future use.

The question of roughening on steep grades was raised by our Chairman and it is indicated in the paper that the original concrete was kept very rough This seems to have met the case so far. I might mention that Ghat portion is not used by bullock-carts to a great extent. It has railway facilities at the top, it has railway facilities at the bottom. But when a bullock-cart does attempt the ascent, it is usually given an extra pair of bullocks

On the question of dowels, it is, I think, a bit too early to have any results, whether they will have any deteriorating effect or not. This is another point which is being watched.

Then the question came up of laying full 27 ft. width without any joint I might mention that the suggestion in the paper, of doing away with the longitudinal joint was on an embankment which for 8 months in the year stands dry and for the other 4 months in many cases stands in a lake due to the monsoon I am not quite certain whether the two circumstances referred to are the same, and whether treatment would be sufficient in the case of a road with this extreme dampness in monsoon.

The question of wear of concrete was raised. I regret to say that

we have no arrangement for recording this in Bombay. We will look to that in future. That seems to be a very useful point.

In regard to widening of the bridges, to give us a clear 20 ft. width, we have in very few cases had to extend the arch. We have cantilevered the parapet walls and also given a footpath.

Chairman:—Mr. Garrod will be glad to reply to other questions by correspondence.

CORRESPONDENCE.

Reply of Mr. Garrod (Author) by correspondence.—

Reply to Mr. J.T. Mehta, Bhavnagar.

With regard to the 6 in. of new metal below the 5 in. concrete slab, reference may be made to my introduction of the paper. Resectioning of the old water bound surface could be done, but it is advisable to leave the old consolidated surface undisturbed, when no additional road metal is to be added.

The uniform thickness of 5 in. of concrete was based on no theoretical calculations. It was fixed in 1938 in conjunction with the Concrete Association of India. Our greatest enemy on a concrete road is a peace time vehicle, the 15 ton steam roller with 10 tons on the back axle. No military vehicle, not even a heavy tank, at present, in this country, is likely to crack a concrete surface.

Due to the extreme shortage of power rollers, as the result of requisitioning for M.E.S. and Government of India works, side widths were not always power rolled. The central joints have only opened out in a few places, in embankments principally in areas, which are very wet in the monsoon. Although kerbing and well consolidated side widths would tend to counteract horizontal movement, it would not prevent it completely. A stronger resistance would be necessary.

Reply to Mr. Mohamed Farhatullah, Hyderabad (Deccan).

The 2 in. size metal might be regarded as small size soling, and as pointed out in the introduction was only used where foundations were bad.

The combined consolidation, in reconditioning and by the passage of traffic, should effect the appropriate interlocking. There has been no abnormal cracking, where the 3 in. metal was provided.

The steep gradients of the Bhor Ghat cannot be circumvented, due to the topographical features of the country, except at very great cost.

The anchorage shown in plate 3 of the paper appear to have effectively counteracted any tendency to "creeping" on the steep slope of the Bhor Ghat. Experience up to the present does not indicate the necessity of additional measures. The base in this case was reconditioned with 3 in. thickness of metal of 1½ in. size.

Reply to Mr. K. S. Raghavachary :—

Para (1).—Reference may be made to page 204, para "Concreting" of the Paper.

Para (2), (3), (4).—The uniform thickness of 5 in. was decided upon in conjunction with the Concrete Association of India in 1938, and was not based on any theoretical calculations.

Para (5).—If the joints are filled properly, bumping will not be aggravated. The modern practice is admittedly to provide an expansion joint at every 100 ft. only and leave construction joints at 30 ft. or 35 ft.

Para (6).—Superelevation was based on the formula

$E = 0.67\ V^2 - R$, limited to 1 in 12, as a greater side slope would be dangerous to animal-drawn vehicles.

where E = elevation in feet per foot width.

V = velocity in miles per hour.

R = mean radius in feet

Horizontal curves were realigned according to Bernouilli's lemniscate.

Widening on curves was carried out to the formula —

$$W = 2\left\{ R - (\sqrt{R^2 - l^2}) \right\}.$$

Where W = extra width

R = radius in feet to outer front wheel.

l = wheel base (16 ft.)

V = velocity in miles per hour.

Anticlines were reduced under the formula found in "Principles of Highway Engineering" by Miley—Page 389

$$L = \frac{s^2 G}{8h}$$

Where L = Minimum length of vertical curve in stations.

s = Sight distance (500 ft.).

G = Total change of grade in per cent.

h = Vertical height in feet of line of site above roadway.

Para (7) and (8).—The actual mix loaded into the mixers at the start of the work was 1.2·4. Subsequently the proportion of sand and small metal was increased and that of large metal decreased as it gave a better density. The excess quantities of metal and sand shown in the rate abstracts were due to wastage between quarry and mixer, including stacking at road side. The eventual mix approximated to 1:2¼·3¾.

Para (9).—Theoretically this was nil, but actually any thickness under 1½ in. was filled with the 1.2.4 concrete. The current rates for 1:3.6 concrete and 6 in. water bound macadam are Rs. 75/- per 100 cubic feet and Rs 10/- per 100 square feet respectively.

Para (10).—The special anchorages are only at the lower ends of the slabs.

FUNDAMENTALS OF SOIL MECHANICS

BY

F.D.L. Woolterton, P.W.D., Burma.

INTRODUCTION

The author has been actively interested in what is now known as Soil Mechanics for the last fourteen years and obtained his first practical experience in 1928-29 when he assisted in some research work on the bearing, cohesion and shear values of clay soils. Those test results, though they can now only be considered as having been useful for comparison, served to accentuate the feeling that very little was known about the soil upon which foundations were laid and, incidentally, that there was considerable difficulty in interpreting such results. Though retaining walls were being designed on the basis of Rankine's formulæ, it was obvious, from a knowledge of cohesion alone, that the results represented values far from the truth, though these values were perhaps true for cohesionless soils under certain conditions. During testing it was clear that the test area and moisture content exercised a considerable influence over the values obtained and that the interpretation of safe bearing values from the curves of load-sinkage was of considerable difficulty Perhaps more than any other fact, the question of the nature of the soil structure was seen to be of considerable importance Working on a London Blue Clay, it was found that the structure might vary, on any one restricted site, from a flake-like form (almost puddled), through tetrahedra (gley and nutty) to thick laminations, with consequent variations in the ultimate bearing value as determined by the apparatus available. Another point which arose during those tests was the varying effect of water on structural elements when their initial moisture content was permitted to vary.

A review of the knowledge available to the foundation engineer at that time was of further interest. Though heavy structures had been successfully built in the past, yet it was only during the lifetime of many of us that the Rankine formulæ (1856) for cohesionless soils had appeared. Paradoxical as it might seem, though neglecting cohesion, these formulæ, give values apparently on the safe side, yet since their introduction, there have been a considerable number of foundation failures. Examination of the many formulæ then in use, showed their similarity in theory but their widely conflicting results.

Since Rankine's time, Re'sal (1910) and Langtry Bell (1915) enunciated theories taking cohesion into account. These appeared to represent a considerable advance though perhaps now, in the light of experience and the study of soil by more advanced principles, these formulæ would require some further revision and amplification. Possibly on account of the Great War, but more likely because of a premonition of the following, Langtry Bell's formulæ were never in general use and neither was his research work continued.

In America the limitations of the Rankine type of formulæ were recognized long ago and these formulæ were largely replaced by empirical formulæ, based on experience, whilst the limitations were examined. This research, stimulated by the modern public demand for increased road milage, involving the construction of low cost roads, gave rise to a more fundamental examination of soils.

By 1926, a considerable amount of work had been done in America, in an attempt to classify soils for the engineer, as it was hoped by this classification that it would be possible to deduce the engineering properties of a soil from its known position in the classification table The properties studied were the chemical and mechanical analyses, colloidal content, moisture content and the voids ratio. Charles Terzaghi[85], to whom engineers owe so much, discussed the results of these investigations, during 1927, in "The Science of Foundations, its Present and Future" and those results were definitely disappointing owing to their conflicting nature and the excessive costs and time then involved. He, however, recommended their substitution by the three simply performed tests of volume change, permeability and cohesion which, to some extent, are dependent upon such properties. For a time these and similar tests prevailed but there was still a strong feeling that these tests could not supply a full understanding of the properties of the soil. As more information was collected, especially in other parts of the world and for soils belonging to widely differing Agricultural Groups, this feeling grew. Road soils carefully classified and subgrades carefully designed did not invariably give the anticipated results There was cracking and sinkage of slabs and—an important point—,even records of road slabs being raised above the construction level. Many engineers in the East and a few in the West have met with instances in which buildings have cracked for the very reason of their lightness. Buildings of medium weight designed in accordance with the most up-to-date information, as regards ultimate sinkage, refused to stop sinking and recorded sinkage values far in excess of those anticipated*. Buildings on piles also recorded unexpected movement The standard tests and investigations could not explain these paradoxes and again research went fundamental.

Working with the kind co-operation of Mr. J Charlton, Director of Agriculture, Burma, the author, in 1935, was led to the conclusion that in addition to the chemical and mechanical analyses, colloids content and voids ratio, the properties of base exchange and moisture movement might even be of greater importance to the Soil Engineer. Since then the author has come to the conclusion that those two properties are closely related, as it is believed, the percentage of replaceable bases, may vary, under suitable conditions, during the year with the moisture content. On the other hand, the moisture movement will vary with the nature of the clay complex or colloids. The voids ratio may also be dependent upon these properties.

The result is that a soil, which under natural conditions is found to be satisfactory, may, when covered by a building or a road slab, act very

*e.g. "Comparison between Consolidation, Elastic and other Soil Properties established from Laboratory Tests and from observations of Structures in Egypt", by G. Tschebotareff, Proceedings of International Conference on Soil Mechanics & Foundations Eng., Vol I., Harvard, 1936.

differently. The moisture movements may be changed and, apart from the direct results of this, the soil complex may be altered by base exchange with a corresponding change in the engineering properties of permeability, elasticity, cohesion and swelling.

Further, experience has led to the belief that the fundamentally important property of the soil is the nature of the clay mineral. If the clay mineral or the mixture of minerals could be easily determined for the foundation soil, as now appears possible, it is believed that the determination of the engineering properties would be greatly simplified once the properties of these clay minerals have been classified.

The inference from the above is that the knowledge of the Agricultural (or Soil) chemist and physicist is of the utmost value to the Soil Engineer and it is in an endeavour to promote an interest in the work of such specialists that this and other publications have been written. If engineering publications on soil problems or even the more recent results of Agricultural or Pedological research were readily available for reference by the Engineering student, this paper would be unnecessary, but unfortunately for the Foundation Engineer this is not the case. Even in Soil Science, which may be taken to have started during the time of Way (J. T., 1850—55), comparatively little is yet definitely known about soil and hence much contained herein must be considered to represent modern-views—in some instances hotly contested—rather than established facts to be set forth with mathematical precision.

PART 1—THE SOIL

CHAPTER I

THE SOIL AND ITS CLASSIFICATION.

The Soil.

The soil upon which the engineer wishes to found his structure, whether a road or a building, may, for engineering purposes, be divided into *primary*, *secondary* or *tertiary* soils, all of which have their rather special physical and mechanical properties*.

Primary soils may be defined as those formed 'in situ' by the direct disintegration and decomposition of the parent rock material. The term parent rock material is used in its broadcast sense and may mean such primary rocks as limestone, granite, basalt or chalk, or may even refer to such secondary parent rock as sand, clay or boulders conveyed some distance from their source by wind, water or glacier action

Secondary soils may be defined as primary soils which have been subject to some definite and prolonged weathering action which has changed the characteristics of the primary soil.

Tertiary soils may be defined as those which, due to changes in the physical or climatic conditions causing the weathering process to be altered, are characterized by a soil profile complicated by showing the properties of both the former and current weathering processes in a more or less pronounced form. In this group may be included soils which are subject, during the same geological period, to two direct and entirely different weathering processes.

In each group the soil material consists, in general, of fragments of the original parent material, semi and fully decomposed parent material, organic matter, micro flora, micro-fauna, air and water. The smaller fragments of the parent rock appear as quartz or mineral silicates the most important of which are the *feldspars*, *micas*, *pyroxenes*, and *amphiboles*. J.M.Van Bemmlin (1877—1904) has shown that these silicates when decomposed by weathering may be considered to fall broadly into two groups which are now designated *Silicate A* and *Silicate B* *Silicate A* is completely decomposed by *boiling hydrochloric acid*. *Silicate B*, whilst not being completely decomposed by *boiling hydrochloric acid*, is decomposed by *hot sulphuric* acid The *Silicate A* material is largely the seat of chemical and physical phenomena.

Organic matter and micro-organisms are, in conjunction with temperature, humidity and rain, responsible for the soil weathering and the geological changes in its properties. The decomposed natural minerals (principally *Silicate A* materials) give place in time to secondary clay minerals which form the basis for the clay type and the clay properties

*The segregation of soils into Primary, Secondary or Tertiary Soils adopted does not follow any recognized agricultural system of classification known to the author, but it appears to be a convenient one for the Soil Engineer.

Agricultural Classification[4].

The agricultural classification of soils is based on the nature of the soil profile, which is an exposed vertical face from the surface down to the unaltered parent material. From this the details of colour, structure, compactness, porosity, chemical and mechanical analyses are collected for the different layers, or *horizons*, down the face of profile. These, with a knowledge of the climate and vegetation, give the nature of the weathering process and, together, enable the soil to be classified under known group names.

In the agricultural world, there is still a certain amount of confusion in the classification of soils[3].

The earliest system was to give to the various known soil types such local names as *rendzinaz, podsols, chernozems, tserozems saline, alkaline* soils, etc., and to endeavour to classify any new soil amongst those known groups whose properties were, more or less, understood.

More recently these groups have been divided into two main classes, i.e., those whose character is still controlled by the parent rock material and those whose character is given by the nature of the current weathering process.

As will readily be seen, this system has the inherent defect that it does not permit of the classification of a new type of soil whose few known properties differ from those of the known types. If a new soil could be completely surveyed and analysed in a few days or even in a few years and if money were available for this, then classification would be easy.

This criticism applies particularly to soils of the tropics and sub-tropics which have not been properly surveyed and whose known properties do not fit in with those of known types. Such better known soils as the *vlei* of South Africa, the cotton soils of the Sudan and the Black-cotton or re'gur of Central India and Hyderabad have been rather temporarily classified as Ground Water Soils (*vlei*) and *Chernozems* (cotton soils) by some, but this arrangement is not by any means generally approved.

There are many other classification systems based on such factors as weathering, rainfall and climate. One of the more recent methods is founded on a peculiarity which appears to enable classification to be divided into two main groups whose profiles do or do not show a calcium carbonate concretionary *horizon* or *horizons*. This has the advantage that the known groups may be classified under one of two main headings and any new groups may be added under local or generally approved names. This system has the further advantage that it can be subdivided into groups depending on either the presence or absence of acid humus and of soluble salts or even on climatic conditions if desired.

Here again the system seems to have its limitations especially regarding the classification of some tropical or sub-tropical soils which

are the result of two distinct weathering processes active during the same geological period

A brief description of the main geological soil groups follows

1. Primary Soils [4].

(a) *Rendzinas*.—Formed by direct weathering of the parent rock chalk Colour varies between brown and black or grey (where chalk still predominates) gradually changing, down the profile to that of the parent rock. Frequent fragments of chalk are found throughout the profile. Structure changes from granular*, at the surface, to nutty with depth. The soil contains free calcium carbonate and is completely saturated with replaceable bases Reaction is alkaline Clay fraction is highly siliceous

Sub-Groups.—

Limestone *rendzinas* with similar characteristics. Limestone Red or Brown, or Terra Rosa—Soils. Less siliceous than *rendzinas* and said to contain free *sesquioxides*, i e. mobile oxides of the trivalent metals of iron and aluminium Hence less exchangeable bases with the possibility of an acid reaction The structure changes from granular to fine nutty.

(b) *Skeletal Soils.*—Coarse primary, or young, soils such as desert sands whose weathering is slow due to climatic conditions; or other soils such as alluvial clay in the early stages of weathering and still bearing the characteristics of the parent alluvium.

(c) *Saline Soils.*—A usually structureless flocculated soil rich in free sodium salts, which are very mobile and whose concentration varies throughout the year. Usually found in arid regions and have been given the name of *Solonchaks.* They are often characterised by a superficial layer of sodium chloride or sulphate during the dry season due to deposition from an upward movement of moisture conveying these salts in solution. It is sometimes asserted that these soils must be accompanied by a water table close to the surface, but the present study of moisture movements in soils throws some doubt on this necessity. It would appear that a soil may be saturated without the presence of a near water table and that movement of salts may take place from this layer of saturation; the saturation being due more to the compactness and high density of the soil and the absence of air than to excess of water These soils are chiefly characterised by weathering due to an upward movement of soil solution, an occurrence in arid regions subject to tropical rainfall of short duration and high intensity resulting in little percolation. Their reaction is neutral or slightly alkaline depending upon the amount of weathering.

(d) *Tropical Red Earths of the Humid Zones.*—Extensively found in Savannah country with a yearly rainfall of 50 to 100 inches and an average yearly temperature of about 70 degrees Fahrenheit With a parent limestone rock, they resemble the *Terra Rosa* and are often completely

*For Soil structure classification see G R. Clarke's "The Study of the Soil in the Field", 1938, Oxford.

void of lime This type is sometimes referred to as a lateritic soil but often such soils contain very little iron oxide and could not form laterite even if the weathering process were favourable. The layers are often of great depth due to the ease with which limestone is weathered in tropical climates and they are sometimes found overlying a yellow or a yellow mottled layer. More generally speaking, there is sometimes found within the red layer a thin one of more reddish earth, marking the limit of air circulation and weathering.

Some of the red soils are friable and some non-friable. The crumbly characteristic of the former is sometimes accredited to the presence of organic matter and sometimes to the sesquioxide character of the soil as opposed to the siliceous nature of the plastic loams. Both, however, are evidence of the same type of weathering. The soil reaction is neutral or slightly acid. Red earths may be formed from a number of rocks, such as gneiss, serpentine and limestone. Their chemical characteristic is the complete removal of bases and, under favourable conditions, of silica as well, producing, if sufficient iron be present, a lateritic soil. The colour is due to the presence of iron, titanium or manganese.

Sub-Groups.—Bright Red; Variegated White, Buff, Yellow or Pink; Variegated, mainly Yellow, sometimes Orange Red, Reddish Brown or Lilac; Lilac or Lavender when dry, and Purple when moist; Brown; White or Buff; Blue-grey; Violet Red or Dark Purple Clays of a similar nature are found on different rock formations.

2. Secondary Soils[4].

(a) *Podsols.*—These are essentially soils of humid climates occurring under heath or coniferous forest land. The parent material may be anything supporting the growth of a peaty type of vegetation, and the soil type is easily recognised by the typical horizons produced by an excess of rainfall over evaporation. It is this percolation, rather than the presence of a strong humus, which produces the strong leaching solution. This solution during its passage down the profile washes away the *sesquioxides* from the bottom portion of the first layer, leaving it a whitish colour and rich in silica, and deposits these *sesquioxides* and some of the humic substances in the second layer. In some instances the second layer is darkened by the deposited humus which in turn is underlain by an accumulation of the deposited *sesquioxides*; in others there is no accumulation of humus in the second layer but an accumulation of ferric oxide forming an iron pan. The third layer constitutes the parent rock.

The essentials for this type of soil formation are a downward movement of moisture and a soil of low base status enabling the humus layer to develop a, perhaps thin, layer of strongly acid humus of a type which will not maintain the base status of the soil.

The soil reaction is acid. Structurally, the characteristics of the profile depend largely upon those of the parent material though generally they appear to be of a granular nature permitting the necessary downward translocation. The result of the downward movement of sesquioxides is to cause a decrease in porosity with depth. A minimum occurs

in the second or at the top of the third layer depending upon the rainfall and the degree of *podsolisation*. There is a tendency towards a laminar structure in the bleached section of the top layer. The lower layer of humus accumulation is occasionally nutty.

Sub-Groups:—

Brown Forest Soils.—Developed under desiduous forest; resemble *podsols* in their free drainage, granular or aggregated granular structure changing with depth to cloddy, and in the high leaching which occurs, down to the parent rock In these soils the leaching refers to the carbonates The *sesquioxides* are mobilised but not translocated and it is the presence of free hydrated *ferric oxide* which gives the soil its characteristic colour. The soil reaction is only mildly acidic and the base status has not been unduly impoverished.

Prairie Soils.—Similar to the Brown Soils and are only formed under *Steppe* conditions Soluble salts, in addition to the carbonates, are leached from the second layer. The upper layer is rich in humus and consequently dark in colour; the middle layer is brownish and the parent material usually greyish The material is porous and the structure is often granular and laminated. The moisture decreases with depth.

(b) *Chernozems.*—Rainfall 15 to 25 inches. These soils are usually rich in humus due to the resistant form this humus type takes and hence the soil is often very dark in colour, though yellow and buff chernozems are said to be known. Owing to their development in arid or semi-arid regions, leaching is incomplete and horizons of calcium carbonate are deposited. The soils are base-saturated and show complete leaching of soluble salts and incomplete leaching of calcium carbonate and sulphate. There is no leaching of the *sesquioxides* or of *silica*. The carbonate is mainly deposited at the bottom of the humic layer and there is occasionally a second layer of concretions at a depth of some fifteen feet. These soils are fairly porous and the upper layer has the characteristic granular structure. With depth, the structure changes to nutty. The reaction is neutral or slightly acid. The parent rock is usually of a *loess* nature but limestone *chernozems* are also known.

Sub-Groups :—

Chestnut Soils.—Similar to *chernozems* but not so fully developed because of lower proportions of humic matter. *Brown and Grey Semi-Desert Soils.* Less developed than *Chestnut Soils.*

Red and Grey Desert Soils.—Porous and eroded soils classified as of the *chernozems* group on account of the presence of layers or crusts of calcium carbonate and/or sulphate (gypsum). Rainfall from 12 to 15 inches, weathering chiefly physical due to complete absence of humus and biological weathering and to scanty rainfall. The first layer is inclined to be laminated and the second may be honeycombed.

(c) *Alkaline Soils or Solonetz*—Derived from the weathering of saline soils during which the sodium salts are removed and sodium takes the place of calcium etc. in the clay complex, by base exchange, leaving a highly dispersed sodium clay. A characteristic feature of this soil is that

it contains mobile sodium bi-carbonate left after the leaching out of sodium chloride and sulphate which causes the sodium-calcium or calcium-sodium clay to deflocculate giving a highly impervious layer. It is thus a very compact soil when moist or wet. When wet the soil is structureless but on drying developes its characteristic structure of a slightly foliated upper layer of a few inches in depth overlying a series of vertical columns, with rounded tops, up to three inches in diameter and four or more inches high. The lower layers are nutty. The rounded column tops are often coated with a fine layer of salts. Normally the lower nuts are extremely hard but in the younger soils, should the layer be exposed whilst the very considerable contraction forces are at work, then these nuts have a tendency to disintegrate and can be easily broken down to dust. The soil then is highly porous, loose and strengthless and it is in this condition that the soil is most easily eroded. Under normal conditions the nut formation, on wetting, returns to the structureless condition. Below the second layer occurs a region of deposition, first that of calcium carbonate, then calcium sulphate and below these the sodium salts. The soil reaction is alkaline.

(d) *Tropical and Sub-Tropical Brown Yellow and Grey Soils of Arid Climates, which cannot yet be classified under known groups.*—Due to the absence of the chief weathering agent (rain) these soils are usually of a sandy nature unless they were originally formed as alluvial. They are often of very considerable depth and of a saline nature with a neutral or slightly alkaline reaction. If the salts are completely removed by leaching, the soil becomes strongly alkaline. In their simple form *horizons* of iron and manganese compounds are formed near the surface. In the grey and brown soils, weak *horizons* of calcium carbonate and gypsum are sometimes found just below the surface.

3. Teritiary Soils[4].

(a) *Laterite.*—In addition to the secondary laterites of the humid zones, tertiary laterites are formed in the intermittently humid zones. Due to the action of the two weathering processes of a weak downward movement of moisture carrying the *sesquioxides* and a stronger movement of *sesquioxides* in an upward direction during the dry season, an accumulation of laterite is formed near the surface.

(b) *Sub-tropical Yellow Saline and Alkaline Soils of a tertiary nature* are sometimes found in alluvial soils in which a layer of lime concretions, of a pisolithic nature, is found near the surface, a layer of massive concretions at a depth of about three feet, a layer of limonite and manganese encrusted pisolite at a depth of about eight feet and a further layer of massive calcium carbonate at a depth of about twelve feet. A more intimate description of such soils is, at present, impossible.

(c) *Degraded Chernozems.*—Represented by forest soils considered to have been formerly steppe land. The carbonate horizon is lowered and the structure destroyed, though nutty structure is sometimes found Slight eluviation occurs and the *sesquioxides* are mobilised and deposited above the carbonate horizon. The typical bleaching found in the top layer of the *podsols* is noticed.

(d) *Black Cotton Soils.*—There are many soils classified as Black Cotton but which widely differ. Their common characteristics appear

to be extreme stickiness when wet, a high coefficient of shrinkage, high exchangeable calcium and the typical *chernozem* carbonate horizons. Iron concretions are sometimes found Here the similarities appear to cease. Whereas in India the Black Cotton soil is thought to be formed from a basalt rock, the Black Cotton Soils of Burma are formed over alluvial beds; whereas the former are highly argillaceous, the latter are inclined to be siliceous and alkaline or saline Attention is drawn to the possible importance of exchangeable magnesium in the Burma Black Cotton Soils

(e) *Ground Water Soils.*—Similar to the *podsols*, but the presence of a lower layer of water-logged soil near to the surface has a marked influence on the profile. This water-logged layer may be due to the formation of accumulation layers with subsequent impedence and hence not an original characteristic of the profile and weathering process. Its presence leads to the formation of a glev *horizon* consisting of triangular prisms of soil with pale-blue, yellow and green streaks, due to alternate oxidation and reduction, with changes in the water level Otherwise these soils are structureless. In the gley *horizon* bog-iron is sometimes found and the soil is very often rich in clay.

(f) *Solods, or Degraded alkaline Earths* are formed by prolonged leaching of *solonetz* in which a process of *podsolisation* takes place In non-calcium soils the upper layer changes from black to grey and the lower portion of that layer changes to the bleached white of the extremely leached soils showing the presence of silica Here the structure is nutty. The soil then changes in colour to brown with a prismatic structure and shows a weak columnar or triangular columnar structure Below this occurs the deposits of calcium carbonate and iron underlain with gypsum. These soils are more porous than the *solonetz*.

In the presence of sufficient calcium carbonate, the soil returns to the granular calcium soil and there is no degradation.

The soil reaction varies from acid near the surface to alkaline with depth.

Conclusions—When viewed from the agricultural aspect, the soil becomes a very different substance from the homogeneous cohesionless or cohesive materials on which the Rankine or Langtry Bell formulæ were based, and the inference is that there are factors, other than friction and cohesion, to be considered

Engineering Classification.

As the engineering properties of the various agricultural soil groups had not been fully studied and comparatively little information, in a 'useful' form, was available, the engineer was forced to develop a classification system of his own. It is, however interesting to add that at the present time there is a powerful movement agitating for the adoption of up-to-date agricultural classification owing to the recent advances in soil studies and to the vast amount of information now accumulated by the soil chemist and physicist[5] The author is in sympathy with this movement which he has recommended in various publications.[1-3]

A. Atterberg, in 1911, suggested a series of empirical tests, which in their modern form are known as the Simplified Soil Tests, for determining two soil properties of great importance to the engineer, i.e., plasticity and shrinkage. In 1912, he was further responsible for suggesting various limits for the fractions determined by mechanical analysis for separating a soil into its component parts, clay, silt, fine sand, coarse sand and gravel. This system became the British and International agricultural classification system. A development of Atterberg's system has given the present one of the American Bureau of Public Roads. Mechanical analysis enables the soil samples to be given a descriptive name such as sand, sandy loam, loam, silty loam, sandy clay loam, silty clay loam, sandy clay, clay and silty clay. It has been found that an expert sampler can almost invariably mechanically classify a sample by feeling it.

These two series of experiments are the foundation for the engineering classification of soils. Together they give a basis for the comparative classification of soils with an estimate of the strength, settlement, shrinkage and such other properties as are of interest to the engineer.

It will be noticed that the above classification is a comparative one only. To obtain absolute results, if desired, further tests are necessary and such tests as those for permeability and strength have been evolved and perfected by Terzaghi and Casagrande. Further, it will be noted that this system gives, for homogeneous soils, a very good idea of the structure and permeability of any particular sample, but unlike the agricultural group system, it does not convey any idea of the soil profile or of the nature of the weathering process and very little of the very important chemical properties, especially the nature of the soil colloids and the way in which shrinkage occurs. All these exceptions may be of considerable importance.

On the other hand the mechanical fractional system of the Bureau of Public Roads has been chosen with considerable care as it separates the soil fractions into those which have distinct mechanical properties and has thus an advantage over any agricultural system, in that it suggests at once certain engineering properties, such as frictional and cohesive strength of the particular samples tested and, if the profile be uniform, the corresponding properties of the site.

The limits for the various fractions, as determined by mechanical analysis, are given by the American Bureau of Public Roads as :—

			Diameter in millimeters.
Coarse sand	..		2.0— 0.25 or 0.42
Fine sand	..	0.25 or	0.42— 0.05
Silt	..		0.05— 0.005
Clay	..		under 0.005
Colloidal Clay	..		under 0.001

NOTE.—The 0.42 limit for the fine sand, corresponding to the No. 40 sieve, is usually adopted when the simplified tests results are also required.

The descriptive classification follows the following proportions[8] .—

	Sand per cent.	Silt per cent	Clay per cent
Sand	80 - 100	0 - 20	0 - 20
Sandy loam	50 - 80	0 - 50	0 - 20
Loam	30 - 50	30 - 50	0 - 20
Silty loam	0 - 50	50 -100	0 - 20
Sandy clay loam	50 - 80	0 - 30	20 - 30
Clay loam	20 - 50	20 - 50	20 - 30
Silty clay loam	0 - 30	50 - 80	20 - 30
Sandy clay	55 - 70	0 - 15	30 - 45
Clay	0 - 55	0 - 55	30 -100
Silty clay	0 - 15	55 - 70	30 - 45

The engineering properties suggested by the various soil fractions are :—

Coarse sand .. Friction, supplying structural strength ; looseness, giving permeability but no capillarity ; non-absorptiveness ; no cohesion , no plasticity, no colloidal properties, open structure ; chemically inert.

Fine sand .. Supplies a bedding for the coarser material ; no appreciable cohesion or capillarity; no plasticity, closer packing than coarse sand ; addition of a little clay or humus produces cohesion

Silt .. No friction ; considerable coarse capillarity ; little or no cohesion, the little being of a temporary nature ; acts as a filler between the coarser material ; the little cohesion, due to the contraction of the minute water films on drying, enables very close packing which retards movement of moisture and air; can absorb small quantities of moisture and may be slightly chemically active and colloidal , shrinkage properties, especially if humus is present ; no appreciable plasticity.

Clay .. No friction ; considerable cohesion due to inter-molecular forces and molecular moisture films ; plasticity, may have considerable fine capillarity; chemically active , said to be crystalline with a definite crystalline structure , shrinkage properties ; compressibility.

Colloids (better described as that fraction of the clay with certain definite colloidal properties). No friction ; impermeable ; plasticity ; cohesion , shrinkage and other colloidal properties ; compressibility if peptised in presence of sodium bi-carbonate ; elasticity if flocculated by calcium bi-carbonate ; colloidal properties more pronounced than those of the clay fraction.

The other Atterberg Tests are for the determination of the *Liquid Limit, the Plastic Limit, the Plasticity Index* and the *Shrinkage Limit*. These tests, with others to be described later, are sometimes known as the *Consistency Tests*. They are usually performed on the material passing the 40 mesh sieve and, unless otherwise stated, are percentages based on the dry weight of the sample i. e., when dried to a constant weight at 105-110 degrees centrigrade. Their values will alter, sometimes considerably, with any variation in the nature and amount of the exchangeable *cations* absorbed on the surface of the colloidal particle.

The liquid limit, is the moisture content of a previously dried and powdered sample which, when placed in a dish about four inches in diameter and divided into two equal sections by a grooving tool, will, on being given a certain number of taps, be just fluid enough for the gap, caused by the grooving tool, to close up after the stated and exact number of blows. The sample is supposed to be just mobile enough to eliminate all cohesion between the particles and to be held together by a small but finite amount of friction which is sensibly constant for each test. It is thus held to represent an empirical measure of the capillary capacity [6-8] of the manipulated sample. It also represents, with fair accuracy, the moisture content of the original sediment if the soil was formed that way [7-8].

The plastic limit, is, the minimum moisture content of a sample of a previously pulverised dried soil at which it can be rolled, by the palm of the hand, into strips 1/8 inch diameter without the strips breaking. The *plastic limit* of such a remoulded sample has a number of significances. The one which is made use of for the purpose of classification is that it is held to represent the moisture content at which the particles will slide over each other under a practically constant force, whilst at the same time, the sample possesses considerable cohesion. It will be noted that the sample is a disturbed one and is subjected to considerable manipulation. Below the plastic limit, the physical properties of the remaining moisture are no longer those of free water. The supporting power of the soil has been proved to decrease rapidly as the moisture content increases beyond the *plastic limit*.

The Plasticity Index is defined as the difference between the *Liquid Limit* and the *Plastic Limit* and hence represents the amount of moisture necessary to destroy the cohesion represented by the *plastic limit*. It is thus considered to represent an empirical measure, for comparison purposes only, of the cohesion and the range of moisture content over which the soil is plastic. In practice the amount of cohesion required is limited by the accompanying plastic range.

The Shrinkage Limit, is, the moisture content below which any decrease in moisture may be accompanied by decrease in weight but no decrease in volume. The *shrinkage limit* test differs from those for the *liquid limit* and the *plastic limit* in that it can be performed either on an undisturbed sample, or a remoulded one prepared from the same material as those for the *Liquid limit* and *plastic limit* tests. The *shrinkage limit* for an undisturbed sample appears to be somewhat higher than that determined for a remoulded sample. This is apparently due to the greater resistance to compression afforded by the soil structure of the undisturbed sample. The difference between the two *shrinkage limits*

is, in a way, a measure of that structure The test results enable a differentiation to be made between expansive and non-expansive soils and represent an empirical measure of the combined effect of cohesion and resistance to consolidation

The determination of the above values, i e, mechanical analysis, the *liquid limit*, the *plastic limit* and the *shrinkage limit* for a very large number of soil samples has enabled American investigators to compile a classification table, and correlation curves, for the grading of soils into seven groups. Determination of the Simplified Test values for a given soil enables that soil to be classified in one of these groups Its general and relative properties are then known and, if the foundation be for a road slab, the necessary foundation treatment, if any, before the slab is laid, can be determined.

Road construction has fortunately, by its extensiveness, supplied such a vast number of results that the classification tables may be used with a considerable degree of confidence. Unfortunately, with buildings this is not so much the case The number of results derived from the study of their foundation soils is obviously very much smaller and, to date, no such simple method of classification cum properties has been found Generally, in their case, other and more definite tests are necessary, though a certain amount of information is undoubtedly available from the classification tables

By way of check on the above discussed classification, based on the Simplified Tests, a further series of empirical tests has been devised. Amongst these are the determination of the following.—

(a) The *Field Moisture Equivalent*, or the minimum moisture content at which a drop of water placed on a smooth surface of the soil sample will not be immediately absorbed but will spread over the surface giving a shiny appearance It gives the moisture content at which the expansive properties of the surface layers are satisfied. It does not, in the test, apply to the lower layers of many samples as certain physical and chemical actions may take place to prevent this It gives for cohesionless soils the moisture represented by imbibitional moisture, fine and coarse capillary moisture The field moisture equivalent represents the combined effect of capillarity and cohesion [8] and gives a fair idea of the amount of water a disturbed soil 'in situ' will freely absorb Hence the difference between the *F M E.* and the *S L* is an indication of the relative shrinkage of soils under field conditions.

(b) *The Centrifuge Moisture Content*, or the moisture content retained after a sample has been drained and subjected to a centrifugal force of one thousand times the gravity, for one hour. With permeable soils all the free water is expelled but with impermeable soils, part of the water is retained on the top surface producing water-logging. It thus differentiates a permeable soil from an impermeable one when the soil is subjected to a centrifugal force of approximately two tons per square foot [6] The results are held to indicate the combined effect of (fine) capillarity, compressibility and permeability [5].

(c) *The Volume Change*, or, the change in volume expressed as a percentage of the dry volume, which occurs when the sample is dried from a predetermined moisture content to that represented by the *shrinkage* limit. For comparative purposes the upper limit is usually taken as the *F.M.E.* when the volume change is known as the Volumetric Change though for other purposes it may be taken to be the *liquid limit*. It represents the combined effect of capillarity, cohesion and resistance to consolidation[5]. *Volume change* is of particular importance in road work as high values result in cracking, the destruction of the cohesion and the allowing of water to enter and soften the road base.

(d) *The Lineal Shrinkage* may be determined directly by experiment or it can be calculated when the Volumetric Shrinkage is known. As an appoximation it may be taken to be equal to one-third of the volumetric change.

Generally, the tests for *Volumetric Change* and *Lineal Shrinkage* are unnecessary as only in certain cases do the values help in classification[6]. The tests can be performed on disturbed or undisturbed samples.

(e) Other values, sometimes determined, are the specific gravity of the soil particles ; the bulk specific gravity or the apparent density of the soil,—usually determined indirectly by calculating the *Shrinkage Ratio* or the ratio of volume change to moisture loss above the *shrinkage limit* which can be proved to equal the bulk specific gravity. The apparent density can be ascertained for remoulded or undisturbed samples and the values obtained are often of considerable interest and value.

The following re'sume' of the test constants for each soil group together with any special characteristics and any treatment required before the soil can be used has been extracted, almost verbatim, from 'Public Roads', Volumes 12, Nos. 4 & 5, June and July 1931 and Volume 10, No. 3, May 1929 and is republished with the permission of the United States Department of Agriculture, Bureau of Public Roads :—

Group A-1. Grading: Material retained on the No. 10 sieve not more than about 50 per cent. The soil mortar, that fraction passing the No. 10 sieve, to consist of clay, 5—10 per cent, silt, 10—20 per cent ; total sand, 70—85 per cent ; and coarse sand, 45—60 per cent. Average effective size approximately 0.01 m.m. and uniformity coefficient greater than 15. The band shown in Figure 1 illustrates graphically the grading of good soil mortars.

Constants ; *Liquid Limit* not less than 14 or not greater than 25 ; *plasticity index* approximately equal to that indicated by curve 2 of Fig. 2 and seldom greater than 6 ; *shrinkage limit* seldom less than 14 or greater than 20 ; and *centrifuge moisture equivalent* not apt to be greater than 15.

Fraction passing the No. 200 sieve—

Liquide Limit about		60
Plasticity Index ,,		26
Shrinkage Limit ,,		36
Shrinkage Ratio ,,		1.3
Centrifuge Moisture Equivalent	,,	49
Field Moisture Equivalent	,,	36

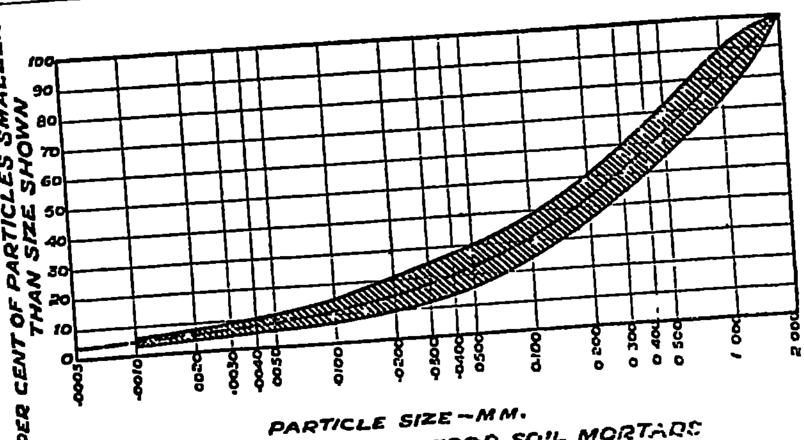


FIGURE 1. GRADING OF GOOD SOIL MORTARS

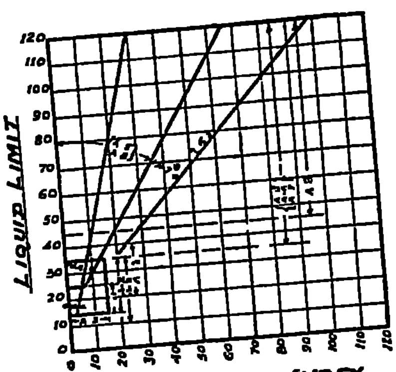


FIGURE 2.

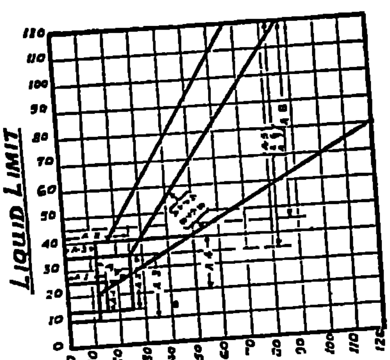


FIGURE 4.

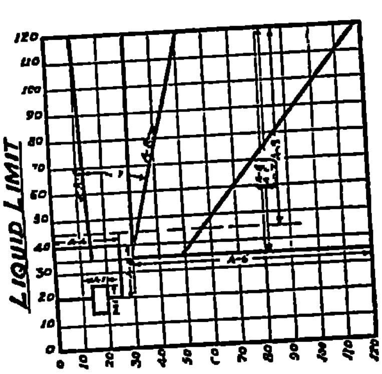


FIGURE 3.

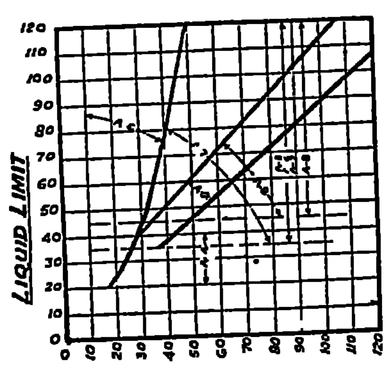


FIGURE 5

Characteristics :—Well graded material with excellent binder: Highly stable under wheel loads, irrespective of moisture conditions: Functions satisfactorily when surface treated or used as a base for relatively thin wearing courses: High internal friction and cohesion ; no shrinkage, capillarity or elasticity.

Group A 2.—Grading : Not less than about 55 per cent of sand in the soil mortar.

Constants : *Liquid Limit* generally not less than 14 or greater than 35 ; a plasticity index of zero with a significant *shrinkage limit* or a plasticity index greater than zero and less than 15 with or without a significant *shrinkage limit*; *centrifuge moisture equivalent* not greater than 25.

Characteristics :—Coarse and fine materials with an inferior binder: Highly stable when fairly dry : Likely to soften at high water content caused either by rains or by capillary rise from saturated lower strata when an impervious cover prevents evaporation from the top layer or to become loose and dusty in dry weather : High internal friction : May have detrimental shrinkage, capillarity or elasticity.

Group A—3. Grading: Effective size not likely to be less than 0.01 m.m.

Constants :—*Liquid limit* not appreciably greater than 35 ; no *plasticity index* ; no significant *shrinkage limit; centrifuge moisture equivalent* less than 12.

Ability of sands to resist sliding when wet, indicated as follows; *Liquid limit* of 10-14 signify beach and other rounded sands which slide easily; *liquid limit* of 30 to 35 indicate rough angular particles which do not slide easily. In addition, *liquid limit* when lower than *field moisture equivalents* indicate materials which flow under partial saturation, when equal to the *field moisture equivalents*, the *liquid limit* indicate average sands which flow under full hydrostatic uplift. *Liquid limits* greater than *field moisture equivalents* indicate rough grained sands which flow only when in a state less consolidated than that represented by the *field moisture equivalent.*

Characteristics :—Coarse material only, no binder : Lacks stability under wheel loads but unaffected by moisture conditions : Not likely to heave or shrink appreciably : Furnishes excellent support for flexible pavements of moderate thickness and for relatively thin rigid pavements : High internal friction, no cohesion : No detrimental capillarity or elasticity.

Group A-4. Grading : Less than 55 per cent sand.

Constants : *Liquid Limit* seldom less than 20 or greater than 40; *plasticity index* not greater than those indicated by Curve 3 of Fig.2; *shrinkage limit* not likely to be greater than 25; *centrifuge moisture equivalent* approaching those indicated by Curve 10 of Fig. 4 between 12 and 50; when greater than *liquid limit,* indicates varieties of soils inclined to be especially unstable in the presence of water; *field moisture equivalent* equal to or somewhat greater than those indicated by curve 11 of Fig. 5, with a maximum of about 30.

Increase in expansive properties generally indicated when *shrinkage limits* exceed 20 and approach those represented by Curve 6 of Fig. 3, especially likely when field moisture equivalent exceeds *centrifuge moisture equivalent*.

Characteristics.—Silt soils without coarse material, and with no appreciable amount of clay. Tendency to absorb water readily in quantities sufficient to cause rapid loss of stability even when not manipulated: When dry or damp, presents a firm riding surface, which rebounds but very little upon the removal of load: Apt to cause cracking in rigid pavements due to frost heaving, and failure in flexible pavements due to low support. Internal friction variable, no appreciable cohesion or elasticity. Capillarity important.

Group A-5. Grading: Less than 55 per cent sand (Exceptions occur).

Constants: *Liquid Limit* usually greater than 35, *plasticity index* seldom greater than those indicated by Curve 3 of Fig 2, *centrifuge moisture equivalent* greater than 12, often lying between Curves 9 and 10 of Fig. 4, not likely to water-log (Exceptions occur). *Shrinkage limit* generally greater than 30 and greater than 50 for very undesirable members of this group. May approach values indicated by Curve 6 of Fig 3 for silts containing peat and approach those indicated by Curve 7 of Fig 3 for soils containing either diatoms or mica in appreciable amount. *Field moisture equivalent* approaching those indicated by Curve 12 of Fig 5 for silts containing peat in appreciable amount and those indicated by Curve 13 of Fig 5 for highly elastic soils containing mica or *diatoms* in appreciable amount. The *Kaolins*, representing good binders are members of group possessing relatively high *plasticity indices* and low *field moisture equivalents*.

Characteristics.—Similar to Group 4, but gives highly elastic supporting surfaces with appreciable rebound upon removal of load when dry. Elastic properties interfere with proper compaction of macadams during construction and with retention of good bond afterwards. Appreciable elasticity.

Group A-6.—Grading: Seldom contains less than 30 per cent clay.

Constants.—*Liquid limit* usually greater than 35, *plasticity index* approximately represented by Curve 4 of Fig 2, *shrinkage limit* not likely to be appreciably greater than that indicated by Curve 5 of Fig 3, *centrifuge moisture equivalent* test generally productive of water-logging: likely to lie between Curves 9 and 10 of Fig 4, *field moisture equivalent* seldom exceeding those indicated by Curve 11 of Fig 5; but may be appreciably less for certain colloidal soils. Volumetric change generally greater than 17.

Characteristics.—Clay soils without coarse material: In stiff or soft plastic state absorb additional water only if manipulated: May then change to liquid state and work up into the interstices of macadam or cause failure by sliding in high fills: Furnish firm support essential in

properly compacting macadams only at stiff consistency: Deformations occur slowly and removal of load causes very little rebound. Shrinkage properties combined with alternate wetting and drying under field conditions are apt to cause cracking in rigid pavements. Low internal friction; cohesion high at low moisture content; no elasticity; possible detrimental shrinkage.

Group A-7.—Grading: Seldom contains less than 30% clay.

Constants: *Liquid limit* usually greater than 35; *plasticity index* varies between those indicated by Curves 3 and 4 of Fig. 2; *shrinkage limit* generally varies between those indicated by Curves 5 and 6 of Fig. 3; *centrifuge moisture equivalent* varies between those indicated by Curves 9 and 10 of Fig. 4; water-logging in *centrifuge* test may not occur even at very high *moisture equivalents*. *Field moisture equivalent* greater than those indicated by Curve 11 of Fig. 5. Relatively low *shrinkage limit* with high *field moisture equivalents* indicating presence of colloidal organic matter. Relatively high *shrinkage limit* indicate the possibility of frost heave.

Characteristics.—Similar to Group A-6, but when moist, deforms quickly under load and rebounds appreciably upon removal of load. Thus, lacks firmness in support, similar to subgrades of Group A-5: Alternate wetting and drying under field conditions leads to even more detrimental volume changes than in Group A-6 subgrades: May cause concrete pavements to crack before setting and fault afterwards. May contain lime etc. productive of flocculation. Possesses elasticity.

Group A-8.—Grading: not significant.

Constants: *Liquid limit* greater than 45; *plasticity index* generally less than those indicated by Curve 3 of Fig. 2; *shrinkage limit* indicated approximately by Curve 6 of Fig. 3; *centrifuge moisture equivalent* between Curves 9 and 10 of Fig. 4; *field moisture equivalent* likely to be greater than those indicated by Curve 12.

Water-logging in the *centrifuge test* is characteristic of the mucks containing clay and colloids, whereas very high equivalents without water-logging are characteristic of peat not more than slightly decomposed.

Characteristics.—Very soft peat and muck incapable of supporting a road surface without being previously compacted or displaced by a fill. Low internal friction and low cohesion. Apt to possess capillarity and elasticity in detrimental amount.

PART II
SOIL CHEMISTRY AND PHYSICS

CHAPTER 2.

CHEMICALLY ACTIVE SOIL CONSTITUENTS AND THEIR IMPORTANCE TO THE SOIL ENGINEER.

Fractions larger than silt are chemically inactive Silt may be slightly active especially if free salts of the alkali or alkaline earth bases are present. By far the greatest activity is to be found in the clay fraction especially that portion below 0 001 m m known as colloidal clay, i e., clay which has certain marked colloidal properties Actually these properties are not always, if ever, complete, so that it is not strictly correct to refer to this fraction as soil colloids.

Most of the deleterious characteristics of a soil, which involve directly or indirectly moisture relationships, depend upon the amount and the nature of the clay fraction and hence on any changes in the nature of the clay complex which may occur. In nature, chemical actions, both ordinary and by base-exchange, may occur in many soils under normal conditions, during the year cycle Such actions may lead to a cyclical or permanent change in the soil's properties Under artificial conditions, such as when the soil is covered by some form of foundation slab the change in properties may be abrupt and will almost certainly be of a permanent nature.

It is therefore essential that certain chemical and physico-chemical properties of the soil should be clearly understood. This involves some fundamental conceptions of soil chemistry and physics which are now presented

CHAPTER 3

THE SILICA-SESQUIOXIDE RATIO

The silica sesquioxide ratio or ratio of the silica content to the ferric oxide plus aluminium oxide, usually expressed as *S/R*, is of considerable value in soil studies At one time it was thought that this ratio could be made the basis for a strict classification of soils but unfortunately under the present definitions and test procedures, this has not yet been found wholly practicable Examples have been met in which two clays of differing constitution gave the same *S/R* ratio [3]. However, as regards the main soil groups, Reifenberg was able to find, from a study of published data, that each of these main groups was represented by a fairly distinctive *S/R* ratio[3]. His average figures were :—

Grey Desert Soils	3.62
Prairie Soils and Tschernozems ..	3.17
Alkali Soils	3.01
Podsols	2.84
Terra Rosa	2.43
Red Desert Soils	2.08
Brown Earths	1.98
Tropical Red Earths	1.73
Lateritic Soils	1.28

The figures given by Byers[17] are very similar to these.

Since the weathering process is only truly reflected in the secondary clay mineral matter, it is usual, in modern analyses, to determine this ratio for the colloidal clay fractions although formerly it was determined for such fractions as those passing the 2 m. m. sieve.

Unfortunately the *S/R* ratio cannot, apparently, be used for the determination of the predominant clay type with any degree of certainty.

Clarke, Ricken and Reynolds[71] discussing the "Importance of the 2-Micron Fraction" say :—"The number of constituents "—(*quartz, calcite, kaolinite, beidellite, muscovite* and possibly *montmorillonite* etc)"—present in the 2-micron fraction will necessarily invalidate its use in many respects. ....The mineral complexity of the fine fraction of the soil presents a problem of great magnitude and it is certain that no fraction of the soil, no matter what the particle size limits are, will be entirely free of considerable heterogeneity of constituent composition. Marshall[5] has adequately discussed the nature of the complexity of the fine fraction of the soil and states that 'the ratio of the silica to sesquioxides does not necessarily indicate even roughly the predominant clay type' ".

CHAPTER 4.

SOIL ACIDITY.

The acidity or alkalinity of an aqueous soil solution may be represented by its *pH* value, that is, by the negative logarithm of its hydrogen-ion concentration.

Electrolytic Solutions, including pure distilled water, dissociate, to a greater or lesser extent, into their *cations* and *anions* and thus exhibit electrical conductivity. Thus, for pure water, :—

$$H_2O = H^+ + (OH)^-$$

The concentration of H^+ ions in a litre of pure distilled water has been found to be approximately :—

$C_H = 10^{-7}$ gramions per litre, for which the negative logarithm, or *pH*, equals 7.

Further, since pure distilled water is neither acid nor alkaline, the hydroxyl ion dissociation must equal the hydrogen ion concentration. This follows since, by definition, an acid solution must have an excess of H-ions over (OH)-ions and an alkaline solution must have an excess of (OH)-ions over H-ions,

$$\text{or, } C_{OH} = C_H \equiv pH = 7.$$

The value of pH = 7 is therefore an expression of neutrality.

(5) Marshall, C. E "The Importance of the Lattice Structure of the Clays for the Study of Soils", Soc. Chem. Ind. 54 (1935).

For any aqueous solution the product :—

$$C_H \times C_{OH} = \text{constant} = 10^{-14}$$ at a temperature of 21 degrees centigrade [10]

Any solution and in particular any aqueous soil solution, will be acid or alkaline according as whether

$$C_H \gtrless C_{OH} \text{ or, } C_H \gtrless 10^{-7}$$

Examples of weak acid and alkaline solutions with their corresponding pH values :—

(a) Acid — $\frac{N}{10}$ HCL — 85% dissociated

$$C_H = \frac{85}{100} \times \frac{1}{10} \text{ gms H-ions/litre} = 10^{-1} \text{ approx}$$

or pH = 1 0 approx.

(b) Alkaline — $\frac{N}{10}$ $NaOH$ — 84% dissociated.

$$C_{OH} = \frac{84}{100} \times \frac{1}{10} \text{ gms. (OH)-ions/litre}$$

$$= 10^{-1} \text{ gms (approx) (OH) ions/litre}$$

$$\text{or, } C_H = \frac{10^{-14}}{10^{-1}} = 10^{-13} \text{ gms. (approx) H-ions/litre}$$

for which pH = 13 (approx)

The acidity or alkalinity of a solution may be determined by either of the following two principal methods of which the latter is by far the more common —

(a) By titration with normal acid or alkali to neutrality, or.

(b) By determination of the pH electrolytically using the platinum, glass, quinhydrone or antimony electrode method The antimony electrode method seems to be the latest and details are given in a paper by C J Schollenberger contained in Soil Science, Vol 41, 1936

The pH of a Soil varies with :—

(a) The amount of organic matter of humus present and its degree of base saturation, i e. with the colloidal humic substances present and the amount of bases absorbed therein.

Humic acid, formed during the decomposition of organic matter, is, in the absence of bases, highly acidic having a pH of 4 or even less It is oxidizable especially in the presence of bases, producing CO_2 and H_2O When bases are present, especially calcium, the acid properties of humus vary from 'mild' to neutral

(b) The amount of mineral acids present The chief mineral acids present, or likely to be present, in soils are :—

$H_2O + CO_2$ acting as H_2CO_3, formed during the oxidation of organic materials and humic acid or by the dissolving in water of carbon dioxide from the atmosphere during rain or formed from the carbon dioxide produced during plant and micro-organic respiration in the presence of moisture[11], and introduced into the soil by percolation

H_2SO_4 formed during the oxidation of organic sulphur compounds, sulphides and free sulphur by certain bacteria and also by direct oxidation of sulphur compounds and sulphides[3,11]

HNO_3 formed during thunderstorms, especially under tropical conditions, and introduced into the soil by percolation.

In addition, phosphoric acid and/or a form of silicic acid may be formed, under certain conditions, by anion exchange[12]

Further, potential HCL, H_2SO_4 and H_2CO_3 may be formed during partial cation exchange in the presence of electrolytic solutions in which the base replaces H-ions from the soil complex or micelle

According to some authorities the amounts of mineral acids present in soils are small but this does not appear to be universally accepted.

(c) The nature of the clay—especially the colloidal clay-fraction. This is expressed by the *silica-sesquioxide* ratio or the *acidoid-basoid* ratio for the clay fraction, i.e $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ or, in view of the work of Mattson, Pugh and du Toit and others, and as expressed by Robinson[3], by the (silica, P_2O_5, humic acid)/(sesquioxide) ratio when humic acid is present in the colloidal clay complex.

Thus desaturated siliceous clays, i.e. clays in which the silica sesquioxide ratio has been, perhaps arbitrarily, fixed as greater than 2, have a lower pH than desaturated clays rich in sesquioxides, i e. those clays in which the silica sesquioxide ratio is less than 2[3]

In the above it is pointed out that silica and the sesquioxides not only form the bulk of the clay fraction but offer the greatest resistance to base exchange and other weathering phenomena The degree of permanentness is $Fe > Al > SiO_2$.

(d) The degree of base saturation of the silt, clay and colloidal clay fractions. The higher the degree of base saturation the higher the pH, but unless some soil alkali or alkaline earth bases, preferably in the carbonate form, be present in free and accessible form the pH is unlikely to rise much above the neutral value of $pH = 7$

Similarly the lower the base saturation or the higher the degree of unsaturation the more acid the soil-reaction

The pH of a soil supplies the engineer with the following information.—

1. Low values of the pH indicate soils with an acid reaction. Any free or ionized potential acid is available to attack exposed steelwork and may, by capillarity, or possibly by vapour transmission, be able to attack steelwork embeded in concrete. This action is rather similar to that occurring when the reinforcement of piles in sea water is corroded by acids formed electrolytically due to temperature differences and introduced to the surface of the reinforcement by capillarity, vapour flow or by electric currents.

2. Requirements in the control of water purification[13].

Apart from the above the pH gives little direct information unless accompanied by further data, as will be seen from the following :—

3 High values of the pH infer alkalinity. Though generally speaking an increase in pH corresponds to a decrease in corrodibility yet if free carbon dioxide be present an alkaline solution may cause as much corrosion as an acid solution [14] Normally an alkaline solution will lead to deposition in, say, a pipe line and cause choking.

4. The pH value is an indication of the base exchange capacity or, more correctly, of the degree of saturation. From its value and a knowledge of the nature and amounts of replaceable bases the amounts of such stablizing materials as calcium chloride, sodium chloride and silicates required to be used in earth road stablization problems, can be estimated for known conditions of leaching. This will be further discussed under Base Exchange.

5. The pH gives some indication of the active weathering process and of the nature of the clay minerals formed by that process. Thus a low pH indicates an active acid weathering productive of siliceous clays ($S/R > 2$) of high plasticity, low friction, high cohesion and moderate shrinkage a neutral or slightly alkaline pH in the humid tropics indicates strong hydrolytic weathering productive of sesquioxide clays ($S/R < 2$) of low plasticity, moderate cohesion (down to a certain moisture content below which the cohesion disappears) and low shrinkage ; a high pH indicates a mild hydrolytic weathering and represents fine grained impermeable soils of high cohesion and high shrinkage The clay minerals for the above progression of weathering degree may, in general, be theoretically considered to vary from those bordering on the *Montmorillonite* group down to those represented by the *Kaolin* group and/or the hydrated aluminium, ferric oxide group. In practice, however, the dominant clay minerals appear to be represented in rather the reverse order, i. e., minerals of the *montmorillonite* group appear to be more common in tropical than in temperate zones and that those of the *Kaolinite* group appear more common in temperate zones.

When the S/R ratio approaches 2, the weathering borders on both the podsolic and lateritic, or, on the siallitic and allitic systems. The two may actually be both active in any one area. This leads to two possibilities—a variation in profile properties within the area and

contradictory test results for any profile. In such soils the difference between apparent and true cohesion may be of even more importance than that stressed by Terzaghi[66], as long ago as 1925. Such soils require considerable further study.

CHAPTER 5.

ELEMENTARY DISCUSSION OF SOIL WEATHERING.

The creation of a soil and the changing of it from one type to another is due to a number of physical and chemical processes, of which the most important is the weathering action by the soil solution. This solution or movement of moisture carries with it certain acids, when it acts in a downward direction, and the strength of these acids depends upon the absence or presence and the nature of the humic matter in the soil surface layers, where humus is the decomposition product of vegetation, animal remains, excreta etc. Various types of humus have differing reactions on the base status of the soil—some have a strong leaching effect on the soil complex, others have a tendency to preserve the base status. The kind of humus produced depends essentially on the vegetation supporting power of the soil and its action on the soil depends upon the base saturation of the soil. If the soil is highly base saturated the humus itself becomes base saturated and the leaching effect may for the time being be nil. If the soil has a low base status then there is nothing to counteract the acidity of the humic substances produced and leaching occurs.

The simplest form of downward moisture movement is represented by rain water with its impurities absorbed as it falls through the atmosphere. Such impurities may include H_2O_2, H_2CO_3, H_2SO_4, HNO_3 and HCl, the most important of which is H_2CO_3 which is also formed within the soil by oxidation, micro-organisms and the decarbonation of organic matter.

If the humus be a strong one the leaching of it by rain is said to produce a solution containing very strong humic acids.

Thus for a low base saturated soil, the soil solution causing leaching, varies from the mild one of impure water to the strong one containing humic acids.

The fraction of the soil which is most subject to weathering is the clay fraction which is composed of a number of units, or micelles, of a fundamental clay mineral or mixture of clay minerals whose properties are, at the present time, being closely examined by the chemist, mineralogist and radiologi[15]. Though these mineral units have reached a fairly permanent mechanical state of equilibrium they are still chemically active and are considered to have the form of compound silicates of aluminium or alumino-silicates of hydrogen, calcium, magnesium, potassium or iron, with each of which may be associated, in an ionic condition, the

cations of other sodium, potassium, calcium and magnesium compounds—each acid radicle having attached to it cations of the earth bases in proportions depending upon the weathering and the nature of the parent material.

Salts of the soil bases produced by chemical action and base-exchange and conveyed downwards by the moisture movement may be adsorbed by the soil complex or micelles by base exchange, i e, an equivalent amount may replace an equivalent amount of one of the complex adsorbed bases according to known rules of preference thus producing a soil complex richer in that base. The salt liberated, if insoluble, is then free to be deposited or if soluble is carried away in the moisture movement to be deposited lower down by such chemical action as reduction, or it may be carried away in the soil drainage.

For a given amount of rain and a given humus, the order of leaching is chlorides, nitrates and sulphates, sulphates of sodium and potassium, the carbonates and sulphates of calcium, carbonates of other bases, iron, aluminium, manganese and silica, though with the latter four the mobility depends upon the pH and may be in the reverse order to that given.

Thus, for the given conditions, sodium and potassium are carried away and eventually disappear in drainage or, if the soil be impermeable or not subject to drainage, a layer of these salts will be deposited at the limit of downward moisture movement. Calcium carbonate is leached out next in the form of bicarbonate which is finally either reduced at the limit of air percolation and deposited as concretions above the sodium salts or is completely removed by the drainage water. With time, or with change in the strength of the leaching solution, iron, aluminium, manganese and silica are gradually attacked, mobilised and deposited in approximately the reverse order to their susceptibility to leaching.

Chemically this is represented by an alteration by base exchange from, say, a calcium clay to a hydrogen clay, in which the prevailing cation is now hydrogen in place of the original presumed calcium If, however, instead of rain water being the cause of weathering, sea-water were to replace it, then conditions would be very different The original clay, on account of saturation, would be turned by base exchange to a sodium clay and the soil bases would be, to some extent, liberated as salts of those bases though after saturation with salt water these salts would not be deposited in well defined horizons

There is another weathering action which is caused by an upward movement of moisture conveying with it an alkaline or neutral solution as compared with the acid feature of the downward movement. Although the exact way in which this upward movement is produced and supported in soils with no shallow water table is not definitely understood and may, in fact, be denied by some authorities, chemists and pedologists appear, in the main, convinced that it does occur and has to occur, to explain various chemical actions such as those causing the deposition of the sesquioxides of iron, aluminium and manganese and the relative

positions of these depositions as they are found in the soil profiles. The constituents of this upward soil solution are the products of hydrolysis such as sodium or calcium bicarbonate, sodium hydroxide, etc., and any soluble salts of sodium which the upward stream may encounter

The sodium solutes may have very definite effects on the soil, the magnitude depending upon the amount of solutes and the leaching of the downward stream. Should the upward movement predominate over the downward movement, they may change the soil character from, say, a calcium to a sodium soil; they may cause the irreversible deposition of such salts as those of manganese and iron which have been mobilised and translocated by the downward stream; they may change an impermeable layer of flocculated clay to a permeable layer or vice-versa. In other words, should conditions be suddenly changed so that the upward stream has a predominating influence, whereas formerly it was only of secondary importance. The soil will be completely altered physically as well as chemically, whereas formerly it was only of secondary importance.

Such changes in a soil are accompanied by structural changes which are of considerable importance to the engineer They effect the soil's permeability and its cohesive and shear properties and hence its bearing value. In addition, the change in chemical properties may cause the formation of salts having a destructive action on an engineering work. The effect may change an elastic clay to a compressible one and vice-versa.

Though under the normal conditions of an established weathering system changes are very slow in temperate regions, they are some forty times more rapid in tropical zones[72] and may be comparatively instantaneous, universally, when the weathering process is suddenly changed as might be the case under a newly constructed road slab.

Chapter 6.

PRELIMINARY DESCRIPTION OF THE CLAY UNIT OR MICELLE.

Probably the best elementary description ever given of the clay complex or *micelle* is by Comber to whose 'Scientific Study of the Soil' the reader is referred. He describes the clay particle as a salt in which the colloidal bodies of the particle constitute the *anion*. This is pictured as the centre part or nucleus of the complex and, being of an *anionic* nature, is negatively charged. The charge is assumed to form an inner sheath of negative *ions* distributed around the *anion* surface. Around this negatively charged inner sheath of the nucleus are attached a number of positively charged *cations* of the alkali and alkaline earth bases forming a charged outer sheath. These outer *cations* form, in the aggregate, the complex cation of the hypothetical salt. The *cations* are not in intimate contact or association with the soil *anion* but exist in varying degrees of dissociation depending upon the magnitudes of the attractive and repulsive forces acting between the *anion* and the respective *cations*. These two sheaths—the inner and the outer—form the so-called *Helmholst* double layer.

The nucleus or *anion* of the clay salt is as complex as the *cation* and is generally considered to be an alumino-silicate, that is, it corresponds to the *anion* fraction of one of many rather hypothetical silicic acids. As will be seen later the colloidal nucleus is even more complex.

On account of the dissociated or diffused nature of the *cationic* sheath it is found that in normal soils the colloidal complexes have a resultant negative charge[16] This is said by some authorities to be due to the comparatively great distance separating some of the more loosely held *cations* from the *anion* nucleus by which the sign of these weakly held *ions* declares the sign of the colloid. A far more convincing explanation for the colloidal resultant electrical sign is that based on the Mattson conception of '*ionegens*'[18] or semi, attached molecules According to this theory the soil *anion* adsorbs from electrolytic solutions certain *cations* which will in turn dissociate their *anions*. It is these partially free dissociated *anions* which give rise to the resultant negative charge.

The value of the negative charge will depend upon, amongst other things, the degree of dissociation and hence on the nature of the adsorbed *cations* It will increase with the number of monovalent *cations*, and decrease with an increase in divalent *cations*.

In those particular soils of a lateritic nature whose silicate has been removed in part or in whole, i.e. clays with a *S/R** ratio of less than two, the colloidal complexes consist largely of aluminium or iron hydroxide *gels* or a combination of both These colloids, although electro-negative, act, in the presence of acids, as if they were electro-positive owing to their property of being able to adsorb a diffuse layer of *anions* In alkaline solutions they revert to the usual electro-negative type *On account of this peculiarity of acting as both electro-positive* or electro-negative colloids they are known as amphoteric colloids or ampholytoids[19].

In general, aqueous soil colloids show the sign of the non-adsorbed or negatively adsorbed *ions* As a particular case, under certain conditions and at a certain value of the *pH*, known as the isoelectric *pH*, the resultant charge may be zero. Under these conditions the colloidal particle carries no dissociated ions

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CHAPTER 7.

BASE EXCHANGE.

The finer fractions of the soil, especially the colloidal clay fraction, possess the property of removing *cations* from solutions of electrolytes, (weak acids, neutral salts and weak hydroxides) in exchange for equivalent amounts of the soil adsorbed but dissociated bases according to laws of preference This process is known as base exchange and applies to both organic and inorganic colloidal materials. It differs from ordinary *chemical reaction, which may also take place, in that* :—

**S/R*=Silica—sesquioxide ratio.

(a) The action is, in general, a superficial one, i e., it is of an *adsorptive* and not *absorptive* nature.

(b) The action is, in general, though not invariably, an interchange of *cations*, i. e. the soil colloidal particle has more or less loosely attached to its surface *ionized cations* of the soil bases—*CaO, K_2O, Na_2O, MgO* and *H_2O* which are exchangeable with the *ionized cations* in the electrolytic solution.

For any definite concentration of electrolyte there is a limit to the amount of *cations* exchanged. Thus, though this exchange occurs instantaneously, or nearly so, it is not a complete exchange. During the process an equilibrium solution is formed around the colloidal particle or *micelle* which prevents further exchange. This equilibrium solution contains the *cations* exchanged from the soil but as yet only partly free together with, perhaps, some *ionized anions* from the electrolytic solution. By repeated leaching with the electrolyte, the equilibrium solutions can be successively removed until complete or nearly complete exchange is obtained. A final washing with distilled water to remove any remaining electrolyte is necessary to render the exchange permanent. This follows from the fact that base exchange is largely reversible. The more pervious the soil under humid conditions the quicker the leaching effect. Hence, *in situ*, the changing of the clay type depends upon the amount of electrolyte available and the ease with which the displaced cations may be carried away in the soil drainage.

The exchange action is said to be accelerated and the total amount replaceable to be increased by successive heating, washing and drying[20] which tends to break up the structure and set free the more inaccessible *ions*. This property is thought to be of considerable importance in the study of tropical soils where these actions are produced naturally and with great frequency.

In general, for average soils, the replaceable bases are *CaO, MgO, K_2O* and *Na_2O* and they are present in that descending order of magnitude. The amounts are, nowadays, expressed in milligram equivalents per hundred grammes of air-dry soil (or parts per 100,000 divided by the equivalent weight). Until quite recently, and often at the present time, chemical analyses have been given unaccompanied by analyses for the replaceable bases. These chemical analyses show the amounts of the alkali and alkaline earth bases in the form of *oxides*, but care must be taken not to confuse these bases with the replaceable bases which are of very much smaller magnitude and of a very different relative order.

Some bases existing in the soil are free or adventitious, others form part of the colloidal clay structure and are available for exchange whilst others are fixed in the crystalline clay structure and are not wholly available for exchange.

Average clay soils, as described above, or those containing only exchangeable calcium, i.e., saturated with calcium, are called calcium clays. Similarly if sodium or hydrogen represented the predominant exchangeable *cation*, the soil would be known as a *Na-or H-clay* respectively. Actually, however, in the case of magnesium and sodium clays

the properties acquired from the presence of replaceable magnesium and sodium are so pronounced that it is not absolutely necessary for the amounts of replaceable magnesium or sodium to exceed those of calcium. This is an important point in engineering soil study since replaceable magnesium and/or sodium are responsible for deleterious properties, especially for low *S/R* values.

If a monionic *Ca-clay* be leached with sodium chloride, base exchange takes place and the action can be expressed as follows —

$$Ca\text{-}clay + 2NaCl = Na\text{-}clay + CaCl_2$$

Similarly, $H\text{-}clay + KCl = K\text{-}clay + HCl$

This action has been generally considered reversible but Russell[4], in his latest edition, draws attention that it is not always wholly reversible as regards the nature of the resulting clay product

If, during leaching, the displaced soil *cation* forms with the dissociated *anion* of the electrolyte an insoluble salt, then that salt is irreversibly deposited If, however, it forms a soluble salt, that salt is free to be carried away by drainage water, to be deposited as a pan at the limit of percolation, or, to enter into further exchange action with the clay complex of that or of a lower or even a higher horizon according to drainage characteristics of the soil, moisture movements and the degree of base exchange stability. This is the reason why, for complete and permanent exchange, a final washing is necessary to remove any free electrolytes.

When the soil's ability to absorb bases is satisfied with combinations of CaO, MgO, K_2O *and* Na_2O, the soil is said to be saturated, but if *hydrogen ions exist amongst these adsorbed bases, the soil is said to be* unsaturated. If the hydrogen *ion* is present in sufficient amount to produce a soil of less than $pH = 7$, the soil is said to be acid. Complete unsaturation exists when all the *cations* are replaced by hydrogen *ions* In general this can only occur in the absence of free calcium carbonate—a primary or secondary constituent of so many soils Percolating water containing carbon-dioxide and sulphur-dioxide, produced as a result of the oxidation of organic and sulphurous compounds, increases this acid leaching as also does heating[21] and washing.

Complete saturation by any particular alkali or alkaline soil base or by a mixture of such bases excluding hydrogen is difficult, if not impossible, to determine. To overcome this, saturation is defined as that occurring at an arbitrary *pH*, usually taken as 7, when the electrolyte has definite and known concentration and nature. For ordinary *in situ* soils, saturation implies an excess of free $CaCO_3$ suitably dispersed and in a form available for exchange

According to Robinson[3] the exchange capacity for colloidal clay varies between the limits of 16.4 m.e.* per 100 gms., (lateritic clay) to

* m e. = milligram equivalents

110·2 (*bentonite*) and for colloidal humus from 250 to 450 m. e./100 gms., illustrating the highly developed colloidal properties of organic colloids.

The replacing power of the *cations*, from their *chlorides*, is :—

$$H > Ca > Mg > K > Na > Li.$$

It has been suggested that the replacing power is connected with *ionic* hydration and hence with the *ionic radii*[3], the replacing power increasing with decreasing radii and decreasing with decreasing hydration. This has been proved under certain conditions for the univalent *cations* with the exception of hydrogen. There is, however, considerable doubt over the nature of the reaction in the case of hydrogen. For discussions on this, the reader is referred to Robinson and Russell. Baver and Horner[22] have investigated this problem theoretically and, basing their investigation on *ionic radii* and *valencies*, have expanded the Jenny hypothesis to give a continuous order of hydration of :—

$$H > Mg > Ca > Li > Ba > Na > K$$

According to this analysis hydrogen occupies the position which would be expected. The order given by Baver and Horner is not the accepted order and refers to a theoretical order based on an equal availability of the soil *cations* for replacement.

The ease of replacement from soils containing only one kind of exchangeable *cation*, i.e., *homionic coils*, is believed by some to be in the reverse order to the replacing power with the possible exception, again, of hydrogen. Thus:—

$$Li > Na > K > Mg > Ca > Ba.$$

Others maintain that the ease of replacement follows the same order as the replacing power [24].

Apart from exchange cations certain soil colloids possess the property of exchanging *anions*. This is known as *amphoteric* behaviour. It is generally considered to occur when the colloid dissociates *hydroxyl ions* on the acid side of its *isoelectric pH*, i.e., the *pH*, at which the particles carry no electric charge. It has been shown that such colloids can absorb phosphates, sulphates and chlorides for which the order of adsorption is $PO_4 > SO_4 > Cl$ [18]. A J. Pugh and M.S. du Toit [12], working with synthetic ferric silicates and phosphates (and thus, by analogy, with aluminium silicates and phosphates, as the properties of these two metals are so alike) investigated the part played by the hydroxyl group of the acidoid component and found that hydroxyl ions could replace the silicate and phosphate ions in equivalent amounts so that the silicates and phosphates of iron and aluminium can be considered as substituted hydroxides Mattson[18, 25] considers the *anions* are not replaced in equivalent amounts but in proportion to the product of their concentration and the association constant.

Mattson says that the displacing power of the *anions* seems to follow the order $OH > PO_4 > SiO_2 > SO_4 > Cl$ [25]

An important property relating to the replacing power of the *cations* is that, everything else being equal, those *cations* with the greatest replacing power are the least hydrated [10]. This results in *cations* with the greatest replacing power producing stable flocculated clays and *cations* with the least replacing power producing sticky, unstable, or highly dispersed clays. As will be seen later, this property is of great interest to the soil engineer.

Of the *cations* present in the soil *micelle*, it is the univalent and divalent *cations* adsorbed on the outside of the *micelle* which are, for the most part, exchangeable. The inside of the *micelle* consists of a much more resistant material in which the alumino-silicate radicle is generally considered to feature. Of the absorbed *cations* inside the *micelle*, aluminium appears to be replaceable when neutral salts are added to acid soils, though there is considerable doubt as to its true replaceability and it seems to be generally conceded that the *aluminium ion* is set free by acids formed by exchange between the colloidal *H-ions* and the cations of the electrolyte and their formation of an acid with *anions* of the neutral salt. It is thought that the acid thus formed attacks the colloidal particle and liberates the aluminium [5,10,11].

Although the case of replacement of *cations* is fairly definitely known it does not follow that all the *cations* present in the soil complex can be replaced with that degree of ease. Total displacement of any *cations* obviously depends upon its degree of accessibility, i.e., upon its position relative to the *micelle*. If the *cations* were all situated on the surface of the *micelle*, as assumed in the Helmholst double layer conception, replacement would follow this order but in some soils a fraction of the *cations* is situated inside the crystal lattice structure of the *micelle* of clay mineral. Magnesium is the most prominent example and many of the *Mg-ions* are inaccessible for base exchange. Grinding of the colloidal material releases some or most of the remaining *ions* — the amount depending upon the degree of grinding [26]. Sodium and calcium *ions*, on this basis, may, as a whole, be the easiest to replace but this will depend entirely upon the type of clay mineral present. This suggests one reason existing amongst chemists for the disagreement, referred to above over the case of replacement.

CHAPTER 8

THE MECHANISM OF BASE EXCHANGE.

In the elementary description of the clay *micelle* given in Chapter 6, the normal type of electro-negatively charged clay *micelle* (S/R greater than 2) is likened to a negatively charged *anion*, forming a nucleus, surrounded by an atmosphere of positively charged *cations* in varying degrees of freedom. These *cations*, in the aggregate, form the complex *cation* of the hypothetical clay salt. A more detailed study of these hypothetical clay salt *cations* and *anions* is essential to understand further properties.

The Helmholst double layer conception is useful in explaining certain phenomena but is nevertheless largely empirical.

The first fundamental property of the colloidal soil complex is its ability to dissociate certain *ions*. For electro-negative colloidal clays the dissociated *ions* are *cations* which form the hypothetical *cation*. The remaining material may be taken, in the aggregate, to be electro negative and is thus likened to a salt *anion*.

The second fundamental property of the colloidal clay fraction is that the material of which it is composed is entirely different from the material comprising the larger fractions. Whereas gravel, coarse and fine sand, consist of rock fragments of the primary soil minerals e.g. micas, quartz, and feldspars etc., the clay fraction, especially the colloidal clay, consists almost entirely of secondary clay minerals formed under the particular type of weathering to which the soil has been subjected. These clay minerals, entirely different from the primary soil minerals, exist in a more or less *gel* form. This is an important fact which reappears in the study of moisture relationships and dependent properties.

Soil colloids have been extracted from known soil groups in various and widely separated parts of the world and examined by X-ray and Microscopical methods as well as chemically. Though much work yet remains to be done, it appears that the colloidal clay minerals are crystalline in character and it is believed that any sample from any particular main soil group will show the same mineral or minerals representative of that group. Though so far, it appears that only one crystalline mineral has been recognised in any soil colloid, it is not yet certain if that is the only one present [27]. If there are others it is assumed that they must be non-crystalline*.

There are certain known fundamental clay minerals resulting, it is considered, as the end products of defined weathering processes and also certain known intermediate minerals. For any particular soil group the extracted colloid may be one, or contain one, of these known pure minerals but it is more likely to be of some intermediate type.

According to Hendricks and Fry[27] the common minerals of the soil colloids are *montmorillonite-beidellite*, *ordovician-bentonite* (or a mixture of *montmorillonite* and *silica*) and *halloysite* with occasional *bauxite*. (Care must be taken to distinguish between the actual soil colloid minerals as found and the pure clay minerals which are only comparatively rarely found in nature).

According to Russell[3] the known pure clay minerals may be grouped as follows:—

(1) *Kaolin* Group comprising *Kaolinite*, *Nacrite*, *Dickite* and *Halloysite*. These appear to be hydrated silicates of aluminium or hydrogen aluminium silicates.

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*For later information see "X-Ray Diffraction Studies of two micron Fractions of some Genetic Soil Profiles" G.L. Clark, F.F. Riecken and D.H. Reynolds, Z. Kristallogr (A) 96, 1937.

(2) *Montmorillonite* Group, consisting of *montmorillonite* or hydrated aluminium silicate containing some calcium and magnesium where some of the magnesium may be replaced by potassium or sodium. This occurs in the *bentonite* soils extensively found in America.

Nontronite—a hydrated silicate of iron, less colloidal than *beidellite*.

Beidellite—a hydrated silicate of aluminium containing some iron. Highly colloidal and a dominant clay—forming mineral.

(3) Unidentified minerals similar to the *montmorillonite* group but with different properties.

(4) Hydrated ferric, aluminium and other oxides.

It may be noted here that there seems to be a little confusion over the grouping of *halloysite*. Robinson[3] and Ross[15] place *Halloysite* or a form of it, known as Crystalline *Halloysite*, in the *Montmorillonite* group.

As pointed out by Kelly, Dore and Brown[2] crystalline minerals are composed of atoms at regularly spaced distances and falling into regularly spaced planes. For alumino-silicates the atoms, or *ions*, are grouped into certain building units consisting of one small aluminium or silicon *ion* surrounded by four large closely packed oxygen *ions* forming what are known as silica or aluminium tetrahedra units. In other alumino-silicates the aluminium *ion* may be surrounded by six closely packed oxygen *ions* forming aluminium octrahedra units. Under certain conditions the hydroxyl *ions* may be found to have taken the place of the oxygen *ions*. For any particular arrangement of the building blocks including any broken bondings, for any given boundary conditions such as cleavage planes and end conditions and for any given conditions of unsatisfied aluminium charges as occurs in certain arrangements, there will be free bonds or charges which are available for bases or *cations* to attach themselves. On this hypothesis the nature of the absorbed *ion* will obviously depend, in part upon the space in the framework available. Amongst the bases which may be absorbed or adsorbed due to the existence of unsatisfied charges must be placed water.

The interplanar spacings form a diffraction grating which appears as a pattern on the X-ray film. A study of these pattern lines, their relative positions and thickness leads to the identification of the clay mineral and any additional atoms held within the structure.

Marshall,[15] in 1936, reviewed the study of the constitution of the clay minerals. He quoted Pauling stating that the minerals are composed of superposed layer lattices of gibbsite [$Al_2(OH)_6$] and B—*cristobalite* (SiO_2) with occasional substitution of *brucite* layers [$Mg_3(OH)_6$] for *gibbsite*. *Kaolinite*, he stated, might consist of one silica and one alumina layer. He quoted Grunner as showing the difference between *kaolinite*, *nacrite* and *dickite* as due to the displacement of the silica layer relative to the *gibbsite* layer; Mehmel as showing that *halloysite* consisted of one hydrated silica layer and one *gibbsite* layer; Hoffman, Endell and Wilm as showing

that *montmorillonite* consisted of two silica layers and one gibbsite layer and that *beidellite* had the same structure including a variation of interplanar distance with water content.

Marshall was able to explain the difference between the chemical and X-ray formulæ for *montmorillonite* on the basis of base exchange phenomena showing that in *montmorillonite* the aluminium is largely replaced by magnesium and that *nontronite* resulted from a replacement of aluminium by iron. For *beidellite*, he showed replacement of silicon by aluminium. Further, he stated, that in clays with a variable crystal spacing, there was room for *cations* to move freely in and out of the crystal lattice at high water content. Whereas Marshall considered that the replaceable basis lie chiefly in the cleavage planes, Kelly, Dore and Brown[26] considered that they lie chiefly in or on the surface[28].

It is these crystalline units which in the presence of moisture usually take the form of colloidal gels.

Properties of the Colloidal Clay minerals.

The *kaolin* group is characterized by a very low base exchange capacity and practically fixed interplanar spacings. *Kaolinite* may be obtained as the end product of the acid weathering of *feldspars*[3]. Members of this group are frequently found in temperate zone soils sometimes together with the unidentified minerals of group three More recently it has been found that if the members of this group are artificially finely ground, their base exchange capacity is greatly increased[26].

Kaolinite, *nacrite* and *dickite* are said to be void of plasticity, colloidal imbibition and not to form gels.[3] Ross[15] stated that the total moisture content of the *kaolin* group is essential to the composition of the mineral and is only lost at high temperatures.

Minerals of the *montmorillonite* group are characterised by high base exchange capacity and a variable interplanar distance—varying with the moisture content. Their water is partly adsorbed and may be replaced by bases. They contain more water than the minerals of the kaolin group and loose more on being heated at 100 degrees centrigrade. They are markedly siliceous and easily dispersible (highly colloidal) Grinding increases the amount of replaceable magnesium and, according to Kelley, Dore and Brown[26], the replaceable potassium and sodium in *beidellite* and potash *bentonite*. This group is largely found in tropical zones, especially in semi-arid soils[26]. It shows marked plastic properties and high capacity for water-absorption. *Montmorillonite*, according to Kelly, Dore and Brown, represents the first product of the chemical weathering of silicate minerals.

The members of the unidentified mineral group appear to be similar to those of the *montmorillonite* group except that their interplanar distances remain constant and do not vary with water content.

The hydrated ferric, aluminium oxide group is characteristic of humid tropical soils.

Hendricks and Fry[27] state that whereas samples of red soils with a

very low S/R ratio were found to contain *bauxite* or *gibbsite* most of the highly ferruginous soils examined contained clay minerals of the *halloysite* type and resembled *kaolinitic* minerals in their shrinkage and moisture relations. They—with Kelly, Dore and Brown—stated that *montmorillonite* formed the major constituent of most *bentonites* and *beidellite* that of some *bentonites* and many soil clay fractions.

Kelly, Jenny and Brown[25], from a study of water relationships of minerals of known composition and crystal structure—based on surface forces which are characteristics of solids and are able to attract water molecules—have been able to throw much light on the factors governing the water relations of the soil's colloidal particles both by analogy and by experiment. They show that soil colloids contained —

(a) Water of crystallization or *OH-ions* as part of the lattice *structure—an independent proof of their crystalline structure*—which they called 'broken bond' water or '*feldspar*' water as *feldspar* was found to be a typical example of this kind of hydration.

(b) Loosely held lattice water which was driven off at lower temperatures than that of the pure minerals which they called 'planar water' or 'bentonite water' after its chief exponent.

Further, their work suggested the interesting relationship that the ratio of water lost at 150 degrees centigrade to the base exchange capacity (Ca-saturation) was practically constant.

Kelly, Dore and Brown[25], and Kelly and Jenny[21] state that the base exchange capacity of *kaolinite* can be increased by grinding but not that of silica, precipitated aluminium hydroxide and ferric hydroxide which have only very low base exchange capacities. In quartz the electro-forces of the molecules are balanced and hence are electrically neutral except on the surface. In other silicates there are in the mineral lattice unsatisfied valences or electro lines of force which are free to absorb bases. They explain the presence of exchangeable bases in finely ground *kaolinite* as believed traceable to the *H-ions* of the crystal lattice and, in the case of *bentonite* clays, they believe the *cation* exchange power to be due to the presence of exposed (OH) groups.

It is interesting to add here that the modern conception of the crystalline character of the colloidal clay minerals largely upholds the old sponge, vesicular or micro-reticulated structure of Nageli (1858), Wilsden and Hardy (1923).

It would therefore appear that the hypothetical soil salt forming the basis of the Helmholst double layer and the elementary conception of base exchange, is more correctly described as a colloidal soil mineral, often an impure form of one or more of the clay minerals, existing in the form of a *gel* and having adsorbed on or in its surface and adsorbed inside its structure *ions*—more or less loosely held—available for exchange. Further, it may be added that the number of *ions* available for base exchange increases with the fineness of the colloidal particle due to the release or creation of unsatisfied forces and to the possibility, especially in the *montmorillonite* group, of *cations* being able to enter the interplanar interstices of the crystalline material under attractive forces.

The presence of the *cations* is due to unsatisfied valences or attractive forces arising out of the arrangement of the atoms in the lattice structure and upon any breaking down of this structure resulting in an increase of surface and unsatisfied forces The type of *cation* to be found in the crystal structure will depend upon the relative sizes of the atoms and the interplanar spacings, and the number of *cations* will depend upon their availability and the magnitude of their attractive forces

In the possible event of part of the soil complex being composed of unknown non-crystalline material—it still is not definitely known if all the material is crystalline—it is necessary to fall back, for the present, on the elementary conception of base exchange to account for its properties—assuming that this material does contain exchangeable *ions* which is of course unknown.

Since silica, aluminium and iron ions are the most resistant to any change and since these are the predominant components of the clay fraction, it is considered that the *S/R* ratio or ratio of *acidoids ampholytoids* should be of considerable value in soil investigation As seen from the above it represents one value of the colloidal particle but is not a complete specification. If the colloidal material were electrodialysed to remove the external replaceable *ions*, the *S/R* and the *silica/aluminium* ratios determined with the replaceable magnesium and potassium after grinding, it would appear that a very complete picture of the clay mineral would be obtained.

Robinson[3] considers that for soils or primary weathering the first product, under humid temperature conditions, is a mixture of hydrated silicates of the general formula :—

$R_2O_3.\ 2SiO_2.\ xH_2O$ having a silica/sesquioxide ratio of 2.

The value of base exchange to the engineer is principally an indirect one On the nature and amount of the exchangeable *cations* depend the moisture relationships and hence the bearing, cohesion, plasticity and shrinkage values etc. This will be discussed further after a consideration of the moisture phenomena. It will suffice for the present to consider a simple example or two of soil stabilization.

Two of the most difficult clay soils to stabilize are natural *Na*—and *Mg*-clays The deleterious properties of *Na*-soils are well known but not so those of the *Mg*-soils. Actually there may be little difference between the two For low values of the *S/R* ratio, *Mg-soils* will have all the disadvantages of the *Na-soils* with the added one of permeability. It is only more recently that *Mg*-clay soils have been studied.

As regards their moisture relationships probably the only similarity between the two lies in their hygroscopicity and possibly in their low shrinkage limits, both of which the author considers to be important properties in soil investigation[30].

The deleterious properties of the *Na*-clays may be represented by the ease with which they, when disturbed, go into suspension or

colloidal solution, resulting in extreme cases of erodibility of banks or loss of the clay fraction in stabilization of road surfaces, their high expansion and contraction; their high moisture holding capacity, their extreme stickiness when distributed and saturated and their extreme hardness when dry.

To stabilize their strength, or stability, and their moisture content to requirements and to reduce their shrinkage, the soil must be stabilized both mechanically and chemically Mechanical stabilization consists of adding suitable material to give a desired proportion between the soil fractions and chemical stabilization consists in changing the nature of the clay in such a way as to change the predominant *cation* and ensure a more constant and suitable moisture content in both wet and dry weather. The chemical materials used are first of all electrolytes for changing the predominant *cation* and secondly deliquescents to ensure a suitable moisture content during the dry weather. To stabilize the moisture content during the wet weather, suitable drainage, side slopes or camber and compaction to maximum density, and hence ensuring minimum percolation, are necessary to prevent the entry of excess moisture which would result in a loss of stability.

From publications it appears that the most popular deliquescent-electrolytes are sodium chloride and calcium chloride There are many others more expensive and hence less common A little thought will show that *NaCl* is not necessarily the most suitable material to add to a *Na-* or a *Mg-clay* It is true that the soil would be improved during the dry weather on account of the added deliquescent properties and to some extent during the damp weather by increased impermeability due to the presence of sodium chloride crystals filling many of the pore spaces but the clay would be still a sodium clay. The best material is apparently calcium chloride which will in time, in whole or in part, change the surface layers of such a clay into a calcium clay and give to it the favourable properties of such clays though it must be again admitted that from the researches of Winterkorn it appears this will depend upon the *S/R* ratio. *NaCl* is probably most efficient for use in *Ca*-clays to stabilize the moisture content, by its deliquescent properties, in the dry weather, thus reducing dust and giving a smoother and more easily maintained surface, and, by its swelling in the wet weather, causing a decreased penetration of water. It would appear essential not to overdo this *NaCl* treatment

As will be seen from various discussions, the addition of calcium chloride in the liquid form, or its presence in a liquid form during rain if added dry, will result in a partial replacement of deleterious *Na* If the soluble *Na* salts displaced are carried away in drainage this partial replacement becomes permanent Further additions of calcium chloride will be necessary to give a complete replacement and to allow for free calcium chloride to act as a deliquescent It would therefore appear that more calcium chloride is required for a *Na*-clay than would be required if sodium chloride had been used and the soil had been a calcium soil.

If drainage is impeded, replacement will probably never be more than partial and the results will possibly not be so good though the addition will still be beneficial.

Another instance of the application of base exchange will be given after a consideration of weathering and moisture movements.

CHAPTER 9.

MATTSON'S THEORY OF ISOELECTRIC WEATHERING.

The general mechanism of weathering has been discussed in Chapter 5 but that review gives no indication of the nature of the secondary clay minerals which may be formed under geologically prolonged given conditions of climate and vegetation The only real and continuous theory put forward to explain the whole mechanism is that of Mattson. The theory may have certain drawbacks—it certainly has its critics—but never-the-less it is a theory and one based on sound fundamentals backed by experiment.

Those engaged in practical work, whether it be in physics or engineering or in any other science, must have some theory on which to base their investigations even though that theory is, for the time being, known to be incomplete. Until a reasonable theory can be modified as required or supplanted by a better one, that theory must form the basis for investigations, which perhaps represents the main difference between American research and that of some of the older nations. The Americans certainly make use of the information available and leave criticism to the cleaning up squads. Rankine's earth pressure formulæ were used for years, although it was perfectly well known that these did not apply to the normally found cohesive soils. They or some similar defective formulæ had to be used or there would have been no scientific basis for the design of foundations. Experience based on the use of these and similar formulæ has resulted in research and the recent advances in Soil Mechanics.

The fundamentals, based on experiment, of Mattson's Theory of Isoelectric Weathering are:—

(a) Soil colloids produced by weathering and consisting chiefly of silica, humus and the sesquioxides of iron and aluminium are, either electro-negatively or electro-positively, charged. Whereas silica and humus act electro-negatively, the sesquioxide colloids act electro-positively in the presence of acid solutions and hence with silica and humus and electro-negatively in the presence of alkaline solutions.

(*b*) Electro-positive and electro-negative colloids can neutralize equivalent charges and thus precipitate each other in part but complete or almost complete instantaneous flocculation only occurs at or near the isoelectric *pH* of the precipitate. For any given mixture of such soil colloids, there is one and only one isoelectric *pH* i.e., only one resulting complex.

This is one of the reasons why the soil clay minerals are so seldom found as pure clay minerals, though it must be admitted that the product is not a final one but will change with the pH or degree of weathering and hence with the time factor. As stated by Mattson "the make up of the complex must be different at each pH and in each new ionic environment". "We cannot unsaturate a soil by electrolysis or otherwise—" (effect of

prolonged acid weathering)— "without altering the constitution of colloidal complex". There is thus possible an infinite series of soil complexes representing a continuous gradation in composition and properties. This is possibly the explanation for Hendricks and Fry stating that the common constituents of soil colloids were *montmorillonite-beidellite, ordovician-bentonite* and *halloysite*

(c) The isoelectric condition presents the most stable product both physically and chemically and this condition is the tendency of any particular weathering process Under such conditions internal electrical forces are compensated and hence are not available to hold diffusible *cations* which, therefore, are free to disperse into the surrounding medium

This condition, though the ultimate aim and tendency in any weathering process, is obviously unstable as regards geological time since the *pH* will vary with additional weathering The precipitated colloids will therefore, in general, be electrically charged and possess exchange capacity.

(d) The solubility of silica increases with *pH* and hence *ionization* increases with the *pH*. Iron and aluminium go into colloidal solution and *ionise* at a low *pH* value

(e) Ferric complexes adsorb and exchange more cations than aluminium complexes, i e , they are more easily hydrolysed

(f) The proportion of silicic acid isoelectrically precipitated by aluminium and iron increases as the *pH* decreases Aluminium hydroxide, being a stronger base than ferric hydroxide, binds the greatest proportion of silicic acid at any given *pH* Aluminium silicate therefore forms at a higher *pH* than ferric silicate. Ferric silicates hydrolyze more readily than aluminium silicates and are completely decomposed at a lower pH value than those of aluminium.

(g) Because it was found that the adsorption and exchange of *cations* at $pH = 7$, by soil colloids, increased with increasing acidoid to ampholytoid ratio, Mattson assumed, as the best explanation, that the acidoids and ampholytoids exist in any soil colloid in partial combination in compounds which are at the same time both acidoid and ampholytoid, that the free and uncombined acidoid valences constitute the seat of *cation* adsorption and exchange and that the free basoid fraction is responsible for *anion* adsorption.

From the above it is possible to foretell, theoretically, the tendencies of some of the main and extreme forms of weathering and soil formation processes As quoted from *Mattson* "Since now the isoelectric composition of this type of material— "(produced by tendency of weathering to form stable compounds under isoelectric conditions)—" varies with the *pH*, we should expect a relationship to exist between the composition of the soil complex and the prevailing *H-ion* concentration of the soil solution. This relationship can, of course only be expressed under conditions of sufficient rainfall to cause extensive leaching and then only in a very general way, because of local differences in climate, geology etc. Another prerequisite for such a relationship to become manifest is that the climatic conditions must have remained approximately the same for a long period."

The theoretically determined tendencies are well borne out by evidence.

The extreme cases of weathering considered were as follows :—

Soils of the Arid Regions, including skeletal soils and some saline and alkaline soils. Coarse rock material and some of the material of the saline and alkaline soils are subjected to hydrolytic weathering (accelerated by heat in tropical and sub-tropical regions) in which fractions of the abundant bases, silica and the sesquioxides are set free. Owing to the alkaline reaction silica will be easily attacked but not so the sesquioxides. The products of hydrolysis will remain in the soil profile owing to scanty rainfall. The small amount of sesquioxides liberated will combine with some of the silica and the remaining silica will be precipitated by the ample supply of bases present The soil complex will therefore have a high *S/R* ratio and be electro-negatively charged. Such soils are rich in bases, notably magnesium, and often belong to the *Montmorillonite* Group.

Soils of the Humid Tropics. Owing to the heavy rainfall and the intense weathering, the bases are mobilised by hydrolysis and removed in the soil drainage. The rapid oxidation of organic matter into weak carbonic acid and water and its almost as rapid replacement ensures a small but constant supply of bases to the soil solution which is believed to remain neutral, or even slightly alkaline, in spite of the humid conditions prevailing. Under these conditions first ferric hydroxide and then aluminium hydroxide are set free but these, especially the former, are unable to precipitate more than a small fraction, if any, of the liberated silica Any silicates present undergo rapid hydrolysis and the soluble products of silica and bases are washed out.

Such soils, rich in sesquioxides, form Red and Yellow Soils depending upon their degree of dehydration. They are sometimes called lateritic soils.

Continuous weathering leads, in time to the complete removal of bases and to an acid reaction resulting in a process of podsolisation in which the sesquioxides are translocated to a lower horizon and deposited as oxides and silicates. With further weathering the aluminium may be removed leaving a vesicular hard soil rich in ferric oxide and known to the engineer as laterite.

Soils of the humid tropics would therefore be expected to have a low silica-sesquioxide ratio, low dispersion, larger particle size, low plasticity and cohesion. Under certain conditions *kaolinite* may be formed as a primary or secondary product.

Soils of the Colder Humid Regions. Although the colder humid regions are productive of a strong acid humus, the hydrolytic weathering, owing to much lower temperatures, is very much slower, and smaller quantities of bases are liberated in any given time. The products of decomposed humus are more resistant to weathering and a strong acid reaction results with a corresponding low *pH*. Under these conditions aluminium and iron will combine with any silica available.

At lower *pH* values, aluminium and iron become ionically mobile under strong acid hydrolysis and may be removed as humates leaving the white horizon, rich in silica, distinguishing the *podsols*.

CHAPTER [illegible]

SOIL WATER

Th[illegible] two schools of thought [illegible] E[illegible] theory [illegible] The [illegible] on the [illegible] founded on the study of [illegible] of [illegible] and [illegible] of [illegible] and the other on a more practical study. In America they have not worried so much about schools of thought but have gone straight to the problem as they found it and consequently their progress in practical application appears to have been considerably better than in England.

The British [illegible] school is well exemplified by the work of Wilsdon, Hardy and Fisher, though they have very powerful opponents.

According to them the soil-water is divided into two main groups, that associated with the colloids or imbibitional moisture, which is fixed or partially fixed by powerful forces, and that associated with the interstices or capillaries or water which is held purely by surface tension forces. Imbibitional water is said to be made up of gel moisture, i.e. that of hydration and hygroscopicity, plus [illegible] water or that absorbed into the vesicles of the colloidal gel. The vesicular moisture results from the [illegible] [illegible] tendencies of Wilsdon and corresponds to the more modern interplanar water of the crystalline structure. Though vesicular water is included [illegible] in the imbibitional water, it does not appear to be held so securely as the other components of imbibition, for, according to Fisher, the interstitial moisture evaporates together with the remaining capillary water, [illegible] that of hygroscopicity.

The American School, represented by Mattson, introduces [illegible] [illegible] should, the [illegible] and colloidal clay property of [illegible] and [illegible] of [illegible].

According to Mattson the soil-water consists of [illegible] water or water of hydration, hydroscopic moisture, [illegible] imbibed water, and water of capillarity. He apparently does not [illegible] [illegible] [illegible] [illegible] and [illegible] [illegible] with that of capillarity which, according to Fisher, [illegible] [illegible]. Mattson's theory is of great help in understanding [illegible] [illegible] and phenomena.

[illegible] [illegible] [illegible] [illegible] [illegible]. These [illegible] must be [illegible] before the [illegible] [illegible] to the phenomena can be [illegible].

According to Mattson's theory, [illegible] both by [illegible] [illegible] [illegible] [illegible] the colloidal particles [illegible] the [illegible] in the [illegible] layer [illegible]

membrane and an *osmotic* force comes into play. During this condition water will be absorbed into the diffused layer and continue to enter till the *osmotic* pressure induced is equal to and is balanced by the electrostatic forces between the diffused *ions* and the colloidal nucleus

One result is, that as a sodium saturated clay is surrounded by a more diffused layer than a calcium saturated clay it follows that the former tends to absorb, by *osmotic imbibition*, far more water than the latter resulting in considerably more swelling. Further, if the nature of the clay be changed by base exchange then the moisture properties will alter. Mattson reviewed other theories of swelling, and discounted them producing evidence in support of his objections. He dismissed the swelling theory or water of imbibition as due solely to hydration of the *ionic* atmosphere, as experiment showed the imbibed water is often far too great to be explained thus except, of course, in those cases in which the induced *osmotic* pressure is small or zero He further dismissed the theory accrediting the enormous swelling of certain bentonites to their one dimensional or micaceous structure by showing that a maximum swelling would be expected, theoretically, from a cubic structure.

The principal difference between the two theories—the American and the British—lies in the respective meanings giving to the term hygroscopic water. According to the British view, hygroscopicity or the ability to absorb moisture from the atmosphere appears to be a variable quantity, varying with the type of soil colloid and the nature and extent of the adsorbed *ions*, whereas from Mattson it would appear that hygroscopicity, or water held by molecular attraction, is practically a constant for any soil and varies only with the nature and extent of the colloidal surface. It thus seems that the British hygroscopic water includes both Mattson's hygroscopic moisture and part of the water of *osmotic imbibition*. The remaining water of *osmotic imbibition*, apparently, is classified as capillary.

It may be added here that both osmotically imbibed water and interplanar water are responsible for swelling and that in the latter instance the swelling may lead to the destruction of the crystalline structure.

Water of hydration or combined water is described by Mattson as that of the hydrous oxides of aluminium, iron and silica and of their hydrous compounds. He states that this water can only be driven off by strong ignition.

Kelly, Jenny and Brown[28], using air dry samples, and basing their research on data concerning the water relations of minerals of known composition and crystalline structure, have been able to give a more fundamental explanation of combined water based on the structural characteristics of the crystalline soil colloids. Working with the known crystalline minerals quartz and feldspars, representing the linked tetrahedra type of structure, they found that most of the water came off at a temperature below four hundred degrees centigrade and that it came off at a more or less constant rate. This type of water was called, by the authors, 'absorbed water' or 'feldspar water' after its chief exponent. The relative rate of loss was the same for all minerals of this type and was said to represent water adsorbed on the exposed surfaces.

For *pyrophyllite* and *muscovite*, on the other hand, there was a comparatively small but uniform loss in moisture at temperatures below approximately five hundred degrees centigrade, but at this critical point there was an explosive-like liberation representing the loss of 'crystal lattice water'. *Kaolinite* and *halloysite* are representative of pure clay minerals of this group.

Bentonites and *beidellite*, generally representing soil colloidal clay minerals, indicated a combination of 'absorbed water' and 'crystal lattice water', the 'absorbed water' being uniformly expelled up to approximately one hundred degrees centigrade and the 'lattice water' being expelled at approximately four hundred degrees centigrade For these minerals the 'absorbed water' exceeded the 'lattice water' in contrast to the results for *kaolinite*, *halloysite*, *dickite* and *pyrophyllite*

Grinding of *dickite* and *chlorite* indicated an increase in the adsorbed water and the grinding of *feldspar* and *pyrophyllite* showed a reduction in the temperature at which crystal lattice water was ejected with a reduction in the crystal lattice water and a corresponding increase in adsorbed water These results show that the total quantity of combined water is difficult to ascertain and that the two types of combined water are in some instances, to some extent, interrelated and variables of the crystal layout. The latter result is explained by the modern conception of crystal structure which states that the combined water molecules exist as *(OH)-ions*. Grinding would therefore increase the surface-held water and hence the absorbed water increases at the expense of the lattice water.

As a result of the *bentonite* tests the authors split adsorbed water into two forms—that typical of *feldspars* (four linked tetrahedra) which they later described as 'broken-bond water', i. e that attached to free bonds or linkages on the surfaces, which comes off uniformly up to four hundred degrees centigrade, and that typical of *bentonites* (*Si-O-Si* planes of six linked tetrahedral) which they later described as 'planar-water', i. e. that loosely attached to stray fields in the crystal planes From this point of view any crushing parallel to the planes causes a predominance of planar water and any crushing across the planes causes a predominance of 'broken bond water'.

Combined water has been found to vary inversely with the *S/R* ratio.

Hygroscopic Moisture is that moisture which is adsorbed from the atmosphere and held, purely by molecular attraction, close to the surface of the particle It is held by very powerful forces which cause compression in the particle and therefore reduce the swelling. The thickness of this film, according to Mattson, is not greater than 4-5 $\mu\mu$. and corresponds to the range of molecular attraction. Its quantity is thought, by Mattson, to be a function of the surface and to be independent of the exchangeable bases though, again according to Mattson, its value for soil colloids increases, in general, with the silica-sesquioxide ratio, which means upon the nature and surface area of the colloids Baver and Horner found the Hygroscopicity to vary with the *S/R* ratio especially for medium humidities where the values were appreciably effected by the nature of the exchangeable *ion*.

According to the British school, hygroscopicity is the difference between the moisture content in a saturated atmosphere and when dry, and is measured as the loss in moisture in oven drying from an equilibrium condition in a saturated or partly saturated atmosphere of known humidity. Mattson, however, assumes hygroscopicity, or molecularly held water, to be that moisture content responsible for the heat of wetting.

It will be noted that although Mattson's conception is perhaps not so clear as it might be, yet in view of Kelley, Jenny and Brown's[28] work the British method of measurement is open to criticism since in drying some of the combined water will be lost. If however it be found that hygroscopic water is the same as, or gently merges into, combined water, then the definitions could with advantage be made clearer by stating an arbitrary temperature dividing the two The same argument applies to the distinctions between hygroscopic and *osmotic* water

Bouyoucos[36] found that the hygroscopic moisture of mineral soils could be extracted, in full, by alcohol, but that in the case of mucks and peats the hygroscopic coefficient determined this way gave a value about one-third less than that found by the oven dry method. He represented the difference in organic materials as due to loss of volatiles and to loss of water of decomposition. He deduced that probably all the hygroscopic moisture exists as physically adsorbed water or film water and does not represent any chemically combined water. The objection to this is that we are really considering relative forces at work which undoubtedly vary with temperature.

If hygroscopic water can be measured as that intake during which heat of wetting is manifest, then the distinction between hygroscopic moisture and *osmotic imbibition* is clear and definite.

Capillary water is that which enters the soil interstices or pores of capillary size and is retained or moves in the soil pores or voids under surface tension forces or surface tension forces plus the effect of gravity. In coarse soils with voids greater in size than capillaries or when water enters soil cracks—both instances involving no surface tension control—then that water is more correctly known as gravitational water. Such water is not considered here as capillary water.

According to the capillary theory of moisture movement. the capillary rise from a free water surface, i.e., one at atmospheric pressure, is given, for a capillary tube of uniform diameter, by :—

$$H = \frac{4T.\cos\alpha}{d.\ \rho.\ g.}$$

Movement up the capillary tube to this height 'h' is caused by the surface tension force between the liquid and the tube surface and equilibrium is established when the surface tension force is balanced by the force of gravity acting on the head of water in the capillary tube The water in the capillary tube is in tension its amount varying with the height of the meniscus above the free water surface. Analysis shows its maximum value to be 4.T/d. Since an active force of this nature calls for a reaction equal and opposite, it follows that the tension forces in the water must be

accompanied by compression forces in the capillary tube transmitted from the water to the tube through the adhesion between the meniscus film and the tube. This, like the hygroscopic moisture, causes a reduction in swelling.

Actually, in soils, the capillary tubes are not of uniform diameter but resemble more a three dimensional series of intersecting bulbous tubes. These changes in cross section effect the capillary height as will be shown later.

In addition to this complication and others concerning the general formula, which really can only refer to inert granular substances, there is that introduced by the *osmotic* swelling. *Osmotic* swelling may be so great as to cause all voids to be filled with the swollen *gel*-like clay material thus eliminating all voids or capillaries. In such an example, as might occur with a saturated sodium clay, there would be no capillary moisture and, for the period in which this state is applicable, there would be no moisture movement by capillarity and hence, in the case of a road surface, no softening of the base from this particular cause.

CHAPTER II.

THE EFFECT OF FREE ELECTROLYTES ON THE PHYSICAL PROPERTIES.

In the chapter on Base Exchange it has been shown that a clay complex will enter into exchange relationships with an electrolytic solution. The amount of exchange will depend—'*in situ*'—upon drainage characteristics, moisture movements and exchange capacity at the prevailing pH. Under given '*in situ*' conditions the electrolytic *cation* will be adsorbed, by exchange, up to a maximum amount. Any electrolyte in excess of the amount necessary for this condition will remain free. The presence of free electrolytes is accompanied, in some instances, by marked changes in the physical properties such as hydration, swelling, plasticity and cohesion. The general effect is one of suppression of the physical properties though, it should be remembered, this is not invariable. It sometimes accentuates the properties but only to a very limited extent and over a limited range of concentrations[37]. The effect of electrolytes on the Consistency Limits has been discussed by Winterkorn[31].

According to Mattson the suppression effect of free electrolytes is entirely due to the valence and concentration of the electrolytic *cation*. It is not due to any neutralizing of electro-static charges nor is it due to any suppression of the dissociation other than that which is to be expected owing to a change in the adsorbed *cations*. In fact, as pointed out by Mattson, electrolytes may increase the dissociation of the colloidal complex.

An interesting factor brought to light during Mattson's researches[38] was that changes in the swelling and imbibition properties, brought

about by base exchange, only take place after a primary drying. Thus the addition of calcium chloride to a highly swollen sodium saturated colloid caused no visible reduction in the shrinkage. It was only after the material had been dried and rewetted that its power to swell was found to have been decreased.

The above discussion is useful for an understanding of the phenomena involved in the use of electrolytes in Soil Stabilization designs.

CHAPTER 12.

SWELLING AND SHRINKAGE

The swelling and shrinkage properties of a soil are of the utmost importance to the soil engineer both as regards shallow and deep foundations.

In road work shrinkage cracks are accompanied by disintegration of the road surface and dusting in the case of earth roads. A cracked road surface permits rain water to enter the subgrade or base which in turn leads to a softening of the road foundation and a loss in stability.

The alternate swelling and shrinkage of soil behind a retaining wall gives rise to 'creep'—a very important factor in many parts of the world. Terzaghi[39] recorded horizontal movements, due to this phenomenon of up to two feet.

Differential movement due to swelling and shrinkage may occur under a building foundation and lead to buckling of the structure resulting in wall cracks and damage to the roofing and flooring Records show that the forces involved may be sufficient to cause complete destruction by slow and continuous disintegration.

Reductions in moisture content, leading to shrinkage, under deep foundations, due to a very dry summer or a sudden change in the ground water level, may lead to the same result

Swelling and shrinkage of clay soils are essentially dependent upon changes of moisture content—there is no magic in these phenomena. There is, it is true, another type of swelling and shrinkage due to dilatancy[63], or the thixotropic properties of some fine grained soils, but this is more a mechanical than a physico-chemical effect. It represents a sudden change in volume due to an artificial change in state brought about by externally applied forces, whereas swelling and shrinkage represent gradual and continuous changes in volume due to gradual and continuous internal forces caused by changes in moisture content.

In the chapter on Soil Water, the moisture content of a soil sample is divided into, that associated with the soil particles, principally the colloidal particles, and that associated with the interstices or capillaries.

Changes in volume accompany variations in amounts of each of these types of water In the former the change is a physico-chemical one, whilst in the latter the action is a mechanical one, due to surface tension forces having the character of an applied pressure The moisture associated with the soil particle, i e, imbibitional moisture may be of very considerable importance in fine grained alkaline clay soils with a low water table Both hygroscopic and osmotic imbibitional water—used in the Mattson[38] sense as amplified by Baver and Winterkorn[10]-are responsible for swelling and shrinkage.

Hygroscopic moisture is associated with the surface of the soil particle but does not cause any displacement of the exchangeable *ions* as occurs with *osmotic* hydration. Its adsorption is accompanied by the liberation of heat—the heat of wetting Baver and Winterkorn have called this type of hydration as *hydratation* The water associated with common colloidal clays they ascribed as chiefly due to hydratation; whereas the hydration of *bentonite* and of sodium or lithium saturated organic colloids was considered as appreciably due to osmotic hydration.

In other words the hydration of ordinary clays is chiefly due to the orientation of water molecules on the particle surface due to the electrical properties of the liquid and the particle surface as is found with non-hydrated suspensoids; whereas with *bentonites* and similarly acting complexes the hydration is the result of *osmotic* hydration as characterizes the hydrated emulsoids Other clays will occupy an intermediate position and will have properties common to both extremes. Mattson did not limit *osmotic* hydration to clays in the presence of organic colloids.

Baver and Winterkorn carried their investigations further and ascribed hydratation as possibly characteristic of approximately spherical particles and *osmotic* hydration as characteristic of plate like particles This clear distinction, although useful to Winterkorn in his further researches, would appear to be rather over-emphasised, if the Mattson conception of *osmotic* imbibition being in a greater or lesser degree applicable to most clays be accepted It is felt by the author that plane electric fields, characteristic of plate like particles, and apparently necessary to account mathematically for *osmotic* hydration could exist on angular particles which are really more spherical in shape than planar. It is thought that at this stage, when there is really little evidence to support this statement, it is unwise to make this clear distinction between clays The so-frequently found statement that certain clays are plate like in shape often leads to the feeling that the deductions drawn from this fact are inconclusive.

Hygroscopicity and Hydratation swelling were found by Baver and Winterkorn to increase with the silica-sesquioxide ratio and with the exchange capacity. Lateritic colloids, though they may absorb moisture into their vesicles, do not swell.

They also found for clays saturated with different *ions* that the hydration decreased with an increase in temperature Hygroscopicity determined for a number of hydrogen saturated clays at constant

humidity showed a very rapid decrease with increase in temperature. This latter fact is of importance when comparing the hygroscopicity of soils determined in different parts of the world. For satisfactory comparison it appears essential that soil physico-chemists should ascertain these results at a mutually agreed upon temperature or, at any rate, the temperature should be given with the data. The same applies in the preparation of the engineering shrinkage-moisture content curves, as the shrinkage limit would, as a corollary, appear to be a function of the temperature.

An interesting point arising out of Baver and Winterkorn's research is that when clay colloids saturated with the common *ions* were allowed to adsorb water the *Li*—and *Na*—clays behaved like *Li*, *Na* and *K* saturated *bentonite*—the action taking considerable time and the amount of hydration being large. *K*-clays on the other hand instead of acting similar to *Na*-clays as might have been expected from their dispersion values, resembled clays saturated with the divalent *ions* '*Ba*', '*Ca*', and the monovalent *ion* '*H*'. With these *ions* the hydration was comparatively small and instantaneous. The *Li* and *Na* clays indicated swelling by *osmotic* hydration in addition to swelling by hydratation.

Whilst microscopic examination suggests that the absorption of water from a free water surface is accompanied by a gradual increase in volume, Bradley, Grim and Clarke found, from an X-Ray Study of the Behaviour of *Montmorillonite* upon wetting[54] that as far as hygroscopic moisture was concerned there was no evidence of gradual swelling For the range studied by them, they found that a series of five apparently definite and discrete hydrates was formed.

CHAPTER 13.

THE MOISTURE-VOLUME, DRYING OR SHRINKAGE CURVE.

A typical drying curve is shown in Figure 19.

Adopting the British system and dividing the soil moisture into that associated with the colloids, i.e. imbibitional and capillary or interstitial moisture, Hardy [33] gave the total moisture as made up of *gel* moisture plus vesicular moisture plus interstitial moisture; where *gel* moisture is that of hygroscopicity for the given conditions plus combined moisture, vesicular moisture is that absorbed in the vesicles of the colloidal *gel* (some of which may produce a little swelling) and interstitial moisture is the capillary and any gravitational moisture.

These moistures are represented in the moisture volume curve as follows :—

(a) The forty-five degree slope, AB*, represents the moisture held by gravitational plus capillary plus a fraction of the vesicular moisture

(b) The curved portion, BC, represents the remainder of the vesicular moisture plus a fraction of the gel moisture.

(c) The horizontal or nearly horizontal portion, CD*, represents the remainder of the hygroscopic moisture plus, under present testing conditions, a small part of the combined water.

Between A and B the change in moisture content is equal to the change in volume or the decrease in capillary volume

During the curved portion, BC, the colloidal particles form a gel-like structure which builds up a resistance to further shrinkage Between B and C the colloidal particles are in a very high state of compression and their resistance to further compression reaches a maximum *within this range A point is finally reached when the colloidal* particles fracture under stress. This is accompanied by a recession of the remaining capillary water to the centre of the specimen with a sudden change in colour and the entry of air. This point is now known as the shrinkage limit From B to the shrinkage limit the strength of the colloidal structure is being mobilised to resist further contraction In this range changes in moisture content are accompanied by a decreasing change in volume until the shrinkage limit is reached after which no appreciable change in volume accompanies any change in moisture content For practical purposes the *shrinkage limit* is defined as the intersection point of the tangents as shown in Figure 19

The connection between the end points of these three fundamental moisture holding ranges and the moisture limits of the Simplified Tests has not been correlated, but if the simplified tests generally represent what they claim then some correlation should be both possible and instructive. Probably the reason for this lack of correlation lies in the procedure of the two series of tests whereby the conditions are not strictly comparable This point is developed in the Chapter 21.

The author has elsewhere[1] discussed the possible relationship between the *shrinkage limit* and the hygroscopicity or, perhaps more accurately, the hygroscopicity plus *osmotic* moisture, but wishes to point out here that Baver and Winterkorn's results show the extreme importance of the temperature at which the hygroscopic determinations are made

The soil engineer would like to be in a position to be able to say that, adopting the Mattson theory of hydration, the curved portion BC of the shrinkage curve represented the *osmotic* hydration and the end portion CD, which is not necessarily horizontal, represented the hydration Unfortunately no convincing proof for or against this possibility has as yet been forthcoming. It is a subject worthy of serious research and the author is convinced that this range CD is of more importance to the engineer than its fixation of the *shrinkage limit.*

*AB & CD represent the liquid and solid curves and BC the transition stage common in physical chemistry and higher mathematics

CHAPTER 14.

DISTURBED AND UNDISTURBED SOIL-STRUCTURE.

As some engineering tests are performed on specially prepared soils subjected to considerable manipulation, it is desirable to consider the difference between an undisturbed soil and a disturbed one or one that is likely to be disturbed. The engineer uses both types and sometimes, possibly, does not differentiate between them Their reactions to load and their moisture movements are very different. Rafts and isolated footings are usually constructed on undisturbed soil below the limits of more active weathering; piles may be driven into disturbed or undisturbed soil but whereas, in the latter case, some soil structures may be unimpaired by driving these piles, other soil structures may be destroyed temporarily or for good ; earth embankments and dams are constructed with disturbed soil and earth roads may be made of disturbed soil or they may be constructed on undisturbed soil which is likely to become disturbed

Most clay soils which the engineer meets, other than surface layers, are very old—even geologically so. From the time of deposition of the coarser particles, accompanied by flocculated ones, a complex network of arch structure has been gradually built up and cemented together by weathering processes. Its strength has been further increased by the gradual process of natural consolidation which has occurred since its deposition. This structural strength is very real, and if this structure be destroyed, as it is when the soil is disturbed, the resulting loss in strength may be very considerable and is thought to be permanent. This loss is often recorded when driving piles into certain clay types Other clay soils have developed a structure through the colloidal nature of their clay fraction. Disturbing such soils results in loss of strength but much, if not all, is recoverable with time. This effect is also often noticed during pile driving operations. Whether the loss in strength be permanent or temporary depends upon the chemical and physical past history of the soil The reality and importance of this loss is often very forcibly indicated by the consolidation or compression test curves.

The above type of soil structure known by some as the micro-structure has received much attention from the agriculturist as he is very interested in the maintenance or the creation if necessary of the particular form of crumb structure.

There is another, a secondary effect of structure. From the Russian and American chemical and physical point of view the meaning of structure is, sometimes, somewhat different.. These agriculturists describe structure according to the grosser visible effects. Clarke [4] calls this the macrostructure. Every soil, on slightly drying, takes up a definite elemental structure according to the soil group to which it belongs. This elemental structure is of great interest, though little studied, and apparently depends upon the horizontal and vertical shrinkage properties of the soil. Macrostructure is discussed in considerable detail by Clarke who also describes some of the typical structures shown by the various Soil Groups.

There are three main structural groups—Granular, including single grain, aggregate grain, nutty, clod or block structure. Columnar, including prismatic and columnar structure; and Plate, including squamose structure It will be noticed that this system depends upon physical and chemical properties and is evidenced through the related shrinkage properties. This is an important aspect especially as this structure remains and is to be found at any period of the yearly weather cycle. One point arising out of this phenomenon is that this structure ought to be considered in the design of foundations For example, one would be justified in assuming that a wall retaining a soil made up of largish cubic blocks would carry less horizontal load than a wall supporting a granular soil, provided it were known that the moisture content never reached a value productive of plastic yield. The possible variation in the ratio of horizontal to vertical shrinkage is believed to be generally evidenced by the macro-structure or in the shape of the natural elements. One very interesting example, though possibly due to a more complicated reason, is the *glei* or *tetrahedral units* or natural elements found in some horizons of London Blue Clay. A rather similar structure is found in Shwebo, Burma, where it appears that expansion and contraction introduces dilatation stresses producing prisms with two faces inclined at angles of approximately thirty degrees to the horizontal. In Shwebo, shear movement is further shown in the profiles by obvious slip planes.

To return from the finite natural elements to the infinitesimally small clay particles or *micells* there is more to learn from the agriculturist. It is frequently stated by engineers that clay is made up of plate or scale like particles which are responsible for certain properties such as *plastic yield*, compressibility and elasticity This may be so but the general way in which it is stated leads one to believe that this is the only form clay particles can take and suggests that the statement is based on the results of a few engineering analyses on certain soil groups only. The agriculturist can tell us that this form is not invariably found It is so for certain alumino-silicates but, clays and colloids resulting from laterisation process have been found to tend to develop a spherical shape. Whilst spherical particles can exhibit no tendency to take up any particular position during or after deposition, scale like particles, on the other hand have been found to tend to orientate on drying, or under pressure, to lie with their flat surfaces at right angles to the plane of maximum principle stress, i e, horizontally in the case of level bedding. It is reasonable to assume that natural elements made up of spherical or laminar particles, or of particles whose shapes lie between these two limits, will act as a magnified particle having the same or dependent characteristics It is also feasible to assume that a spherical particle will expand equally in all directions whereas laminar particles will not. This aspect is further considered in Chapter 15

In general it appears that :—

(1) *The shrinkage limit* is greater for an undisturbed sample than for a disturbed one

(2) The shearing resistance is greater for an undisturbed clay sample than for a manipulated one.

(3) Disturbance interferes with the established capillaries resulting in a smaller swelling volume change for the disturbed sample.

(4) For any voids ratio, or moisture content, if the sample be saturated, the load carried by the undisturbed sample will be greater than if the sample were disturbed.

CHAPTER 15

LINEAR SHRINKAGE

It is often assumed that linear shrinkage may be taken as approximately equal to one-third of the volumetric shrinkage but no mention is made of the possibility of a varying ratio of horizontal to vertical components Experiment suggests that an equal ratio of horizontal to vertical shrinkage may be far from the truth and that the actual value appears to be dependent upon the soil type The early results of research indicate that for a natural element of sodium clay the horizontal and vertical shrinkages are not equal, but their ratio, instead of being unity, may be of the order of two to one in the undisturbed state With a natural element of calcium clay the ratio appears to be more nearly equal to unity The possibility of such variations was foretold by G. R Clarke from theoretical considerations of soil structure. Clarke is a soil chemist not an engineer. The author has reported elsewhere[42, 43] on a soil in which this property of an unequal ratio seems essential to help to explain certain movements in buildings.

Clarke considered this question from the point of view of its effect on the formation of the soil natural elements He based his particular analysis on the orientation properties of soil particles, a clay whose natural element was observed to shrink more in a vertical direction than in a horizontal direction and upon differential wetting.

If the ultimate clay particle be spherical in shape it will settle in any manner and there is no reason why expansion and contraction should not be the same in any direction. If, however, the ultimate clay particle be of plate-like form, it is known it will tend to orientate itself, in time, to lie with its plane surface horizontal. It is conceivable that such horizontal plates will swell in one of two ways or in a combination of both. They may swell principally by *osmotic* hydration when the maximum effect would be expected to occur in the vertical direction; or they may swell by hydratation when, owing to its thinness, it is possible that the maximum effect may be in a horizontal direction. This of course assumes that hydratation swelling can apply to plate like particles which seems contrary to Winterkorn's mathematical reasoning.

Another explanation is suggested by Mattson's "The Laws of Soil Colloidal Behaviour. VIII—The Forms and Functions of Water"[35], which does not necessarily involve the scarcely proven theory of the plate-like structure of certain clays.

Assume a uniform intensity of rain over an evenly graded area of an easily dispersed and high swelling homogeneous clay soil. Such

downward capillary flow, as occurs, as distinct from gravitational flow, will be at a uniform rate The dimensions of the area over which the rain falls may be considered as infinitely great compared with the depth of capillary flow.

(a)' Conditions towards the completion of wetting, vide Figure 6. In any horizontal plane within the band of vertical capillary flow there will be no capillary meniscus and hence no change in the capillary tension and compression in the soil. Owing to *osmotic* imbibition and swelling the already small capillaries will tend, for a time, to become smaller instead of larger, introducing an increased vertical compression. This vertical compression, which is believed may be considerable, will in turn decrease the *osmotic* swelling. During wetting, therefore, it appears that the horizontal swelling may exceed the suppressed vertical swelling

(b) *Condition during drying*, vide Figure 7 During drying there would be compression both vertically and horizontally—the horizontal capillaries splitting into lengths as determined by the soil's resistance to shrinkage. It seems justifiable to assume that the horizontal capillaries will be longer than the vertical capillaries. If this be correct then there would be a tendency for the soil to buckle horizontally as would a long slender strut under compression.

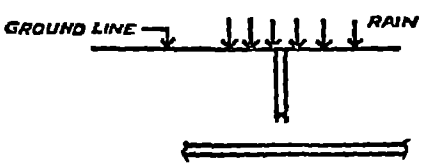


FIGURE - 6

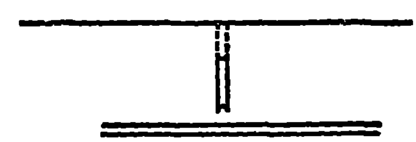


FIGURE - 7

The above suspected phenomena have its applications in practice. If a soil swells more in the vertical direction than in the horizontal, or if the swelling be equal in both directions, then the phenomenon is believed to be relatively unimportant Should, however, the horizontal swelling be greater in the horizontal direction the induced buckling effect may be disastrous for lightly constructed buildings. Differential wetting and drying may play an equally or even more important part.

The author has recorded a yearly up and down movement, in one part of a lightly constructed building, of as much as 0 85 inches.

Swelling Pressure.

The phenomenon of swelling pressure was very forcibly drawn to the author's attention during an investigation into the cause of certain failures of buildings constructed on a sodium-like clay soil. Whilst searching for information, details were found of the cracking of a reinforced concrete beam, held between two piles, caused by the swelling of the soil under this beam during an overnight rain. Calculations show that the soil, in swelling, must have imposed an average minimum load of over three-quarters of a ton per square foot to produce this cracking. Later the swelling pressure, for this soil, was measured by specially

designed apparatus and found to be about one and half tons per square foot in directions both parallel and perpendicular to the plane of bedding

Kruyt[73] refers to the swelling pressure of *gels*, and says that information suggests it is primarily caused by capillary suction in the *gel* structure. He mentions Posnjak's measurements of the swelling pressure of raw Para rubber in different organic liquids which reached enormous pressures for the amount of liquid absorbed at the start. His apparatus was, however, only capable of measuring forces up to seven atmospheres. The Freundlich-Posnjak formula quoted for the swelling pressure appears to be the *osmotic* pressure formula adapted to the case of solvated colloids, i.e., to allow for the diffused double layer characteristic of soil colloids.

Hauser[74] whilst agreeing that *osmosis* plays a part in certain swelling phenomena, considers the problem to be too complex for any fundamental answer, for the time being

The swelling pressure is of importance to the engineer because, when appreciable, differential wetting means that the soil will load the structure whereas, usually, the structure is considered to load the soil Unless the building be strong enough to take this load the building will crack. It is problematical whether for such conditions a raft, other than a square one specially designed, can ever be satisfactory.

Winterkorn,[31] in a discussion on the water adsorption and swelling of sodium clays, in reply to the question "Does that mean that swelling would not take place in a soil with large swelling properties and low energy, if the soil be under pressure ?", replied "Quite true. If the outside pressure plus the mechanical resistance to the entrance of water equals the *osmotic* pressure around the soil particles, then the soil will stop swelling".

This, as regards buildings, is the experience of the author[43].

CHAPTER 16.

COMPARISON BETWEEN THE MOISTURE CONTENTS, THE SWELLING & CONTRACTION OF SODIUM & CALCIUM CLAYS.

Some very interesting hygroscopic moisture relationships were quoted by Baver and Horner[22]. They pointed out that, for low humidities, the order of hygroscopic moisture content was :—

Ca–clay > H–clay > Na–clay > K–clay, whereas at high relative humidities the order was partially reversed in :—

Na–clay > H–clay > Ca–clay > K–clay.

For medium humidity values, they quoted :—

H–clay > Ca–clay > Na–clay > K–clay.

The presence of sodium amongst the exchangeable *ions* tended to lower the hygroscopicity especially at low humidities whereas it was increased by *H*, *Ca*, and *Mg ions*

It would appear that these relationships should be kept in mind when selecting a deliquescent material for use in stabilization work. It suggests a slight general advantage in favour of the use of calcium salts.

Another point referred to in Baver and Horner's paper was the difficulty in understanding why *Mg* - and *Ca* - clays often contained more water than *Li* - and *Na* - saturated clays, whereas one might expect the reverse They ascribed this property as due to variations in the *ionic* radii. It is true that their results apply only to hygroscopic and combined water but an examination of published data reveals that some alkaline soils may not only absorb less water than calcareous soils but may actually show less swelling or shrinkage It is only intended here to restate some of the controlling factors influencing the results.

(a) The results for undisturbed soils will be very different from those for disturbed soils, such as powdered samples, which may be used for the laboratory determination of certain water relationships The difference is due to the destruction of the soil structure, the creation of larger pore spaces and the creation of a completely different capillary system The higher water limits determined for ascertaining the amount of water held or the shrinkage for site and laboratory tests will thus vary very considerably This upper limit can, in the laboratory, be determined by a number of empirical tests but in the field the agricultural Field Capacity test is undoubtedly the only satisfactory one.

(b) The lower limit, taken as the shrinkage limit in engineering, which is believed to be related to the hygroscopicity, also depends upon whether the sample be disturbed or undisturbed though the difference is now very much smaller

(c) The difference between these two limits gives the water uptake productive of shrinkage. The relative amounts will depend upon the procedure adopted The shrinkage depends upon this difference times a quantity equal to the apparent density of the dry sample which again depends upon the state in which the sample is tested.

(d) When an already dense alkaline clay absorbs water *'in situ'*, from a free water surface, *osmotic* swelling may be sufficient to fill completely the voids and capillaries leaving no room for any capillary absorption This will have the effect of reducing the moisture holding capacity The time interval is also important Winterkorn found that with powdered samples of monoionic Putnam colloids it took 150 minutes before the *Li* —and *Na* —saturated samples were able to take in, per gram of colloid water equal to that absorbed by Ca—and H—saturated samples The moisture content for the latter samples had then reached approximately their maximum values whereas the former continued to absorb water up to a period of 4320 minutes before they reached their approximate maximum values.

(e) The swelling depends upon the amount of colloidal clay and the swelling, in c. c. per gm. of colloid, increases as the *S/R* ratio increases.

(f) For *monionic* soil colloids the swelling, for any given colloid, decreases in the general order :—

$Na > Ca > H$, provided the swelling is not in any way suppressed.

(g) The combined water decreases as the *S/R* ratio increases.

(h) The hygroscopic moisture increases as the S/R ratio increases and is effected by the nature of the exchangeable *ions*. It increases with the humidity and decreases with increase in temperature. The hygroscopic coefficient is lowered by the presence of *K* and *Na* but is increased by the presence of *H*—, *Ca*— and *Mg*—*ions*. This apparently applies to all but high relative humidities.

In hot dryish-zones, where alkaline soils are frequently found, the moisture contents probably fluctuate between the limits of hygroscopicity, which in such cases would be low, and full *osmotic* hydration. Such a range would entail a full cycle of '*in situ*' swelling and shrinkage and accounts for the large cracks to be found in these soils. In the more temperate regions, where calcium soils are more plentiful, the moisture contents normally vary between values both representing the presence of capillary water. In such soils the changes in volume are due to capillary forces and, though the magnitude of these changes may be greater than those for alkaline soils, they do not, in general, crack except during very dry summers.

Sideri[69], working with a columnar *solonetz* found that for powdered samples screened to pass a 0.25 m.m. sieve, the average adsorption water was very slightly increased after a preliminary saturation with *Na* and slightly decreased when treated with *Ca*. His values for undisturbed samples were much lower than for any of the powdered ones.

In contrast to these water adsorption results, he found the swelling volume change for the undisturbed sample to be approximately double that for the pulverised.

CHAPTER 17.

VAPOUR PRESSURE.

In addition to gravitation and capillary movements, water may also move through a soil in the vapour form. Levedev and a few others have drawn attention to the importance of this mode of water transmission in some soils but little serious research seems yet to have been devoted to it possibly because of its relative unimportance and extreme slowness in other soil groups.

To give some idea of the mechanism involved a few of the laws concerning vapour pressure are reviewed. Some of these involve the presence of curved surfaces. Now these curved surfaces are present in

soil water in several forms. There is the concave surface associated with the ends of the capillary fringes both at the surface and above the water table. Concave surfaces are also present in the water wedges which may occur between soil particles, whilst convex surfaces exist in the imbibitional water surrounding the particles. As the convex surfaces surrounding the particles and the concave surfaces between the particles can apparently coexist there appears to be an anomaly here which has yet to be explained.

When the different phases are in equilibrium :—

(1) For a concave surface the vapour pressure just above the surface exceeds the pressure just inside the surface by $2\,T/r$ where 'T' is the surface tension and 'r' is the radius of the surface

For a convex surface the vapour pressure just above the surface is less than the pressure just inside the surface by the same amount

(2) In a closed surface, free from any gas other than the water vapour, the vapour pressure over a $\frac{\text{concave}}{\text{convex}}$ surface is $\frac{\text{less}}{\text{greater}}$ than the vapour pressure over a plane surface by $\left(\frac{\sigma}{\rho-\sigma}\right)\frac{2\,T}{r}$ where σ = density of the saturated vapour and

ρ = density of the liquid

If an inert gas be present, in addition to the water vapour, a correction is necessary.

Either of these two conditions may occur in a soil during the wetting and drying stages

Condensation.

(a) Will occur over a concave or convex surface when the vapour pressure is greater than that required for the conditions of equilibrium

(b) Will tend to occur in any material containing fine capillaries which possess the property of being wetted by the liquid This may occur even when the vapour is unsaturated.

(c) May take place on flat surfaces when the vapour is saturated

Vapour pressure conditions are the controlling factor in the use of deliquescent materials in soil stabilization work

The vapour pressure over a solution of calcium chloride and water is less, for given conditions, than that over water alone, so that there is less tendency for the calcium chloride water to evaporate. For the period in which the vapour pressure of the calcium chloride solution is

less than that corresponding to the relative humidity, the solution takes up moisture from the atmosphere until the vapour pressure of the solution is equal to that of the relative humidity. When the temperature rises the relative humidity drops, water evaporates from the solution until a new equilibrium point is reached, though the action is slower than with water Similarly, as the temperature decreases or the relative humidity increases, water is absorbed.

CHAPTER 18.

THE VERTICAL MOVEMENT OF MOISTURE AND WATER IN SOILS.

The way in which moisture and water move in soils is so readily assumed and yet of such obvious importance that some discussion is not out of place.

Very little is as yet definitely known about moisture movements in cohesive soils—whether it be by percolation of gravity water, capillary flow or by distillation. Even the meaning of the level of the water table leads to dispute and another term—the phraetic surface, i. e. the level at which the soil water is at atmospheric pressure, has been adopted to clarify the position.

In temperate climates it is readily supposed that the raising of the water-table, i e. the level at which water will stand in an open well, is due to the addition of water by seepage during a rainy period. This contention is, in general, disputed. It is correct in the case of cohesionless soils and may be correct for clays in arid regions where the soil is riven by deep cracks. It may also be correct for swampy soils with a high phraetic surface.

The one school maintains that the rising of the ground water is due to direct percolation or condensation; the other school maintains that it is due to variation in the pressure conditions within the soil.

King[44] (in a most remarkable paper published in 1898), Harris and Turpin[45] (1917), Ototzky[46] (1921), and Larsen[47] (1933) have all demonstrated the pressure theory, whilst agreeing, in principle, under suitable conditions, to the temperature gradient flow, i. e. from a warm soil band to a cooler, of Bouyoucos. They all agree that unless the ground water level (or the phraetic level of Ototzky and Larsen) is shallow, there always lies a non-saturated or dead layer between the capillary zone overlying the ground water and the temporary capillary zone created at the surface during rain or any temporary inundation.

Ototzky stated that infiltration due to rain to considerable depths was rare and then only occurred when water could remain on the surface or where there were fissures in the soil. His extensive observations shew that during rain the well level was depressed and that it was not till after a storm that the level rose. In the event of a storm and no rain, the level would rise and not fall.

The extent of the temporary capillary surface zone following a rain rarely exceeds five feet, it might be negligible, and its maximum influence on the moisture content of the soil seems to be limited (presumably only in cohesive soils) to a depth of six or seven feet and only occurs then after a heavy rain. Light precipitations have apparently no appreciable effect[45].

The soil air, owing to the fineness of some (cohesive) soils, may move very slowly and may be, in effect, entrapped by the soil grains and the soil moisture. The degree in which the soil moisture can hold the air depends upon the pressure With a decrease in pressure air released expands and is free to act on the soil water producing a downward movement of the phraetic surface and expelling water in the vicinity of any well[44,47].

Pressure conditions in the soil may be changed by variations in barometric pressure. King [44] found that an increase in barometric pressure of one inch caused a depression of five inches in the ground water level (well level). The phraetic level, owing to increase in pressure, is raised and not lowered .

This hypothesis has considerable support and undoubtedly helps to explain many observed phenomena but, as pointed out by Russell,[48] certain observers have been unable to prove the theory by direct measurements of pressures, possibly, it is suggested, because, in their case, there were certain local conditions arising, which invalidated the hypothesis. It is again stressed that each soil must be considered on its own merits, no two soils are exactly alike and the difference between the soils of difference groups is very considerable.

Capillary Moisture. The question of measurable downward capillary movement has been generally discussed above. That the extent of downward movement in cohesive soils is often very limited, though aided by gravity, has been shown by many observers and is now generally accepted.

The reasons for this are as follows :—

(a) The presence of any impermeable layers.

(b) The creation of an impermeable layer by hydrolysis.

(c) The formation of a surface mulch which may prevent the ingress of moisture either by the chemical formation of an impermeable layer or by the physical means of the entrapment of air below.

(d) The slowness with which water enters a dry soil.

On drying, the surface supply of moisture is lost and the downward capillary flow ceases. The capillary moisture near the surface is lost by evaporation and the rest remains for a considerable time as suspended apillaries subject to thermal movement.

Upward Capillary Flow. The way and the extent in which this acts is very definitely a function of the soil type. The manner in which it acts is unsettled; the extent is known to be more limited than that of downward capillary flow and various investigators would appear to limit its extent to about four or five feet for cohesive soils.

Possibly, the reason for the doubt in the way it acts is due to not dividing up results into those applicable to a shallow phreatic surface and those in which a dead layer occurs. If this is done it would appear that in the first example moisture rises from the phreatic surface in the usual capillary manner and replaces moisture lost by evaporation. In the other example evaporation is replaced by capillary moisture, not by the upward movement of the capillary fringe, but by an evaporation from the upper surface of the capillary fringe which gradually recedes into the soil.

The upward movement from a deep phreatic surface acts similarly to that of the movement from a shallow phreatic surface, only its extent would appear to be further limited by the absence of possible freedom of air circulation by which an upward movement would entail the creation of a partial vacuum retarding the capillary flow and also by pressure conditions within the dead layer. There is a further limitation imposed by the diameter of the widest pore space as opposed to the narrowest in downward flow.

The above considerations of capillary flow strictly apply to the coarser capillaries, conveying moisture in quantities and at rates which can be measured. Movement in the finer capillaries, should they exist, is much slower. Both rate and quantities are difficult to measure. Here the action seems to be similar to that of distillation.

Any moisture reaching the water table by capillarity or distillation raises both the phreatic surface and the well level, as opposed to the unilateral effect of the variation in pressure.

The Bouvoucos Effect.—Bouyoucous demonstrated that, under certain conditions of moisture content, water will move, in a homogeneous soil, from a warm area to a colder, due to difference in surface tension forces at the extremes of the moisture belt. Emerson[49] used this phenomenon to suggest that the thermal movement of capillary moisture is always in an upward direction. It may possibly be so under certain conditions such as a shallow phreatic surface and with certain soil types under suitable climatic conditions but its general application is hardly creditable.

Distillation.—Is an extremely important phenomenon and gains in importance as the soil approaches an arid type. Though recognised for some time, this effect received little attention till revived by Lebedev[50,51] in 1930 and Chaptal[52] in 1934.

Distillation is a movement in water vapour form and is controlled by conditions of vapour pressure. It is quite distinct from capillary flow.

Movement of moisture by distillation or transpiration occurs due

to changes in the vapour pressure of the soil air-moisture system with the 'a priori' that as long as the soil contains moisture above the maximum hygroscopicity the relative humidity of the soil air-water system is 100 per cent; that the more arid the soil the less the relative humidity of its air, that the vapour pressure increases with temperature and that the soil air and the atmospheric air are two distinct phases.

As long as the vapour pressure of the soil air-moisture is greater than that of the atmosphere in contact with the soil then evaporation occurs and 'vice versa'.

According to Lebedev [50], his results for arid soils indicated that for such soils —

(1) When the moisture content exceeds the maximum hygroscopicity:—

(a) In all seasons, except winter, moisture is evaporated from the surface during the day At night, owing to the cooling of the soil surface, the vapour pressure of the surface soil is, in many cases, less than that of the atmosphere and, in such instances, vapour enters the soil and condenses

(b) During winter the distillation movement was found to be upwards

(2) When the moisture content is less than the maximum hygroscopicity, which is seldom so for a depth greater than two or three inches, moisture carried by the humid monsoon winds enters the soil in very considerable quantities If the soil vapour pressure is greater than the atmospheric vapour pressure there will be some evaporation which rapidly decreases. A dry soil layer is said to decrease and possibly to prevent evaporation.

Vapour entering soil from the atmosphere condenses but is still available for movememt as pressure conditions change. That is, it moves according to temperature gradients. These gradients vary due to daily changes in temperature and the seasonal lag. Thus in winter the general movement is in an upward direction, whilst in summer, during the day, moisture is lost both upwards and downwards from the surface layer, and, during the night, the surface layer receives moisture both from the atmosphere and from the soil below to a depth corresponding to the level of the maximum soil temperature. This band of maximum soil temperature looses moisture both in an upward and downward direction.

Lebedev [51] stated in another paper that suspended capillaries could not rise to replace moisture lost by evaporation, unless their moisture first turned into the film state He further estimated that the daily movement of capillary moisture due to temperature changes was very small and that in the arid regions tested most of the water movement was due to vapour movement

According to Keen[51], daily fluctuations of temperature practically ceased at a depth of three feet and that this layer is subject to seasonal fluctuations only The same figure is given by Vageler[72]. The more modern feeling amongst some authorities is that in tropical areas the seasonal temperature fluctuations may extend down to from twelve to twenty feet.

Chaptal's adsorption theory[52], though stated by him to be distinct from distillation, appears to be a special case of Lebedev's water vapour theory. According to Chaptal, considerable amounts of moisture, especially in hot climates, can enter the soil even when the soil is warmer than the air. Movement takes place by soil adsorption of hygroscopic moisture and appears to fall in with Lebedev's case of moisture content less than the maximum hygroscopicity.

PART III.

CHAPTER 19.

NOTES ON FRICTION, COHESION, HYDROSTATIC UPLIFT AND DILATANCY.

A Resistance to Sliding or Rupture, Friction and Cohesion.

1. Friction[55], is the mechanical resistance to movement when a non-sticky mass is about to move, without rolling, in a direction parallel to some applied line of force, across another or similar mass. The formula connecting the weight 'W' of the mass about to be moved and the applied force 'F' producing this condition may be given by :—

$F = \mu . W.$, where 'μ' is the coefficient of friction between the two surfaces—similar or dissimilar in composition or homogeneity.

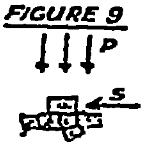
For cohesionless soils, about to sheer along a surface within their mass, this formula is not always correct in so far as the value of 'μ' may be found to vary instead of being constant—a fact which goes far towards explaining the reasons for the long discussion which has arisen over the angle of friction and for the difference between the old angle of repose and the new angle of internal friction.

To take a very simple example, assuming the material to be clean, coarse, sharp sand, it is obvious that the particle of sand 'a' in Figure 8, representing an uncompacted condition, would require a greater horizontal force to move it parallel to the line of the acting horizontal force over the grains 'b', 'c' or 'd' than would be required under the conditions illustrated in Figure 9, where the sand particles have been previously compacted, the interfaces are more regular and the vertical component of movement is eliminated*.

*All soil grains including clays tend to consolidate with their two longest axes at right angles to the compacting force or maximum principal stress. Hence with compacted sands there is little difference in shearing strength between any two planes but with clay there may be a considerable difference owing to the plate like formation of many clay complexes.

FIGURE 8

FIGURE 9



And yet both conditions may occur during loading, but whereas the former bears a resemblance to the determination of the angle of friction from the 'angle of repose', the latter is more truly representative of loadings of, say, greater than one ton per square foot as met with in design and corresponds more to the much smaller 'angle of internal friction'.

The question of interlocking, or the degree of compaction, must obviously effect the angle of friction. This is a general condition and applies to sliding of like or unlike bodies over each other.

For a solid body, say a stanchion base or the base of a reinforced concrete retaining wall, constructed on a cohesionless medium, another, though closely allied, factor arises. For increasing ranges of vertical loading the following types of potential failure, under a horizontal or shearing force, arise :—

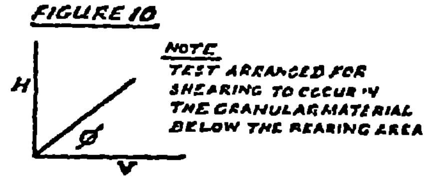
(a) Concrete over granular material

(b) Granular material (that just below the bearing area) over like granular material.

(c) Formation and sliding of cone or wedge of shear in the granular material, if such a cone or wedge can be formed, i.e. where the size of the base is very large compared with the grain size. For smaller ratios or relatively large sized grains, such as large gravel, interlocking, arching and the shear resistance of the grains causes the formation of a truncated cone support, on spread lines, almost monolithic with the foundation, which under heavy loads make shearing or sliding almost an impossibility. The force of this was demonstrated in some early experiments on shear (1928) in which the author participated.

For granular materials, the general shape of the vertical load-horizontal shearing force diagram, for low vertical load was :—See Figure (10).

FIGURE 10



This was expected and the value of the angle 'ϕ' determined corresponded closely with the angle of repose.

When, however, higher vertical loads were used the graph became, for sand, either that shown in Figure (11) or that shown in Figure (12).

FIGURE 11.

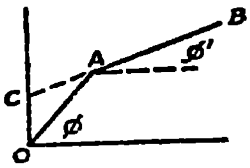
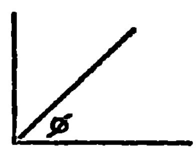


FIGURE. 12.



where the more usual condition as illustrated by Figure (11) was not anticipated. The soil had an apparent cohesion.

By careful repetition of the lower loadings it was sometimes possible to obtain further points on the extension line AC of Figure (11) indicating, that in practice there might be little difference between friction and cohesion and that the two were, to some extent, bound up in each other. This aspect is further considered below.

The angle ϕ_1 Figure (11) is the true effective angle of 'internal friction of,' and not ϕ which corresponds closely to the 'angle of repose'.

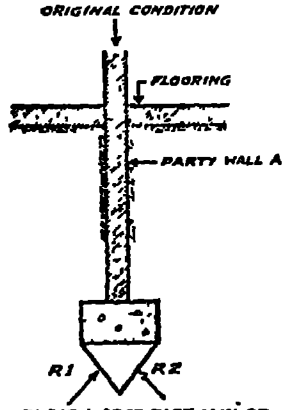
In well conducted modern tests the difference between the slopes of OA and OB, of Figure (11), is said to be due to interlocking and compaction, where the compaction is completed by the time the vertical load 'A' is reached.

Another explanation for this discontinuity at 'A' is ventured, which may have a much closer relationship with '*in situ*' conditions than modern tests, though the two explanations are closely allied.

Throughout the range of loading OA any sliding, or tendency to slide, occurs over the direct interface between the load and the loose sand or by shearing along a plane in the loose sand close to the interface, depending upon the condition of the interface. This was observed in the small scale experiments. By the time the load 'A' is reached the shear cone or wedge is formed and tends to become monolithic with the loading area — the degree depending upon the roughness between the bearing area and the sand and on the applied load. Any movement or shearing then requires that the wedge of shear be moved bodily with the loaded area and an approximate condition of normal shear along the interface over a compacted sand is simulated. An examination of actual failures shows that this condition does occur in practice.

To take a fictitious example, wall 'A' is considered to be a heavily loaded party wall and reconstruction of an adjoining building might require excavation down to or below the party wall foundation. Figures (13) and (14) represent the conditions before and during reconstruction.

FIGURE 13

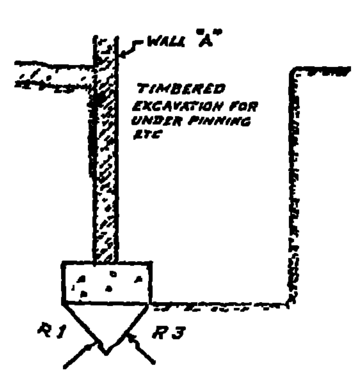


SHEAR WEDGE PARTIALLY OR WHOLLY FORMED & KEPT IN EQUILIBRIUM BY RESISTANCES

R 1 = R 2

FIGURE 14

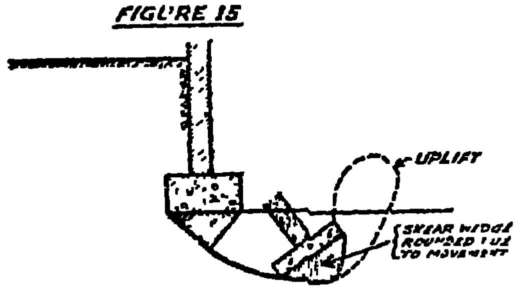
CONDITION DURING EXCAVATION



R 3 & R 2 = R1

It will be seen that the result of excavation will be to diminish or reduce to zero the resistance R_2 acting against one side of the wedge of shear already formed Hence unless suitable timbering is designed to take the earth pressure on the wall plus the horizontal component of $(R_1 - R_3)$ plus any other secondary stresses, then a special case of conditions similar to those occurring along the line AB of Fig. 11 is introduced and failure may occur. Similarly the vertical Component of $(R_1 - R_3)$ must be considered Such a failure would be represented by Fig. 15 (dotted lines) in which the shear cone or wedge, in a rounded form, follows the loaded area or foundation.

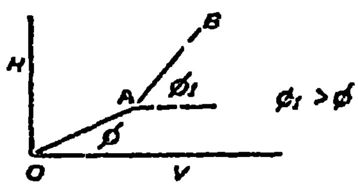
FIGURE 15



The condition shown in Fig 12 is a possible concomitant of any small scale tests not controlled by modern developments in testing apparatus, though it may conceivably occur in practice with certain combinations of vertical load and moisture content of the soil Whether or not this be so, it is obviously desirable to design for the conditions of Figure 11 which have been well proved.

For shear tests on gravel the following type of curve was frequently given, see Fig 16, in which the discontinuity indicated an increase in the angle of slope.

FIGURE 16

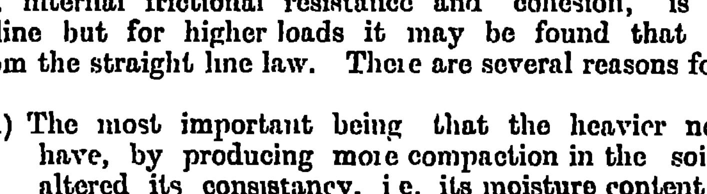


The range OA represents sliding of the bearing area over the gravel which is not fully consolidated until the load 'A' is reached after which the various factors mentioned in (c), above, are introduced. Any sliding then is of gravel over gravel.

2. *Cohesion*, is a measure of the stickiness or adhesion between two like or differing cohesive materials along and parallel to the plane to be tested, or mechanically, is the resistance to shear along that surface when it is subjected to no normal loading. When the surface be subjected to normal load the cohesion still exists within limits and, as will be seen below, may vary from its mechanical definition value.

In the shear diagram for a cohesive soil, see Fig. (17), the coefficient of cohesion is represented by the shear intercept for zero vertical load-stress. It is a shear stress value.

FIGURE 17.



For the lower range of normal loading the curve of total shear force, i.e. internal frictional resistance and cohesion, is generally a straight line but for higher loads it may be found that the points depart from the straight line law. There are several reasons for this:—

(a) The most important being that the heavier normal loads have, by producing more compaction in the soil materially altered its consistancy, i e. its moisture content is reduced, and a reduction in the moisture-content has been shown by Cooling [56] and others to increase the cohesion. A corollary to this is that the cohesion, and hence the shearing resistance, will vary with variations in moisture-content throughout the year for soils situated above the ground water level. The difference may be very considerable. For similar reasons the cohesion and hence shear resistance may vary with depth, due in this case to both changes in pressure and moisture-content.

(b) The value of the cohesion varies with the soil structure and any disturbance of that structure, such as the driving of piles

on the site or on an adjoining site; earthquake shocks, dilatancy caused by shrinkage or contraction stresses in the soil etc.

(c) According to the Hogentogler conception of the moisture film surrounding the soil complex or micelle [57] the ratio of free to adsorbed moisture of hydration, at constant moisture content, decreases with decrease in temperature and vice-versa. This results in a greater viscosity with decrease in temperature and hence increased cohesion and stability. The cohesion is thus found to vary with the temperature. Cyclic variations in temperature occur to possibly a depth of 20 feet—they have not yet been thoroughly investigated but a necessary precaution in modern testing is that the cohesion test should be carried out at a standard temperature.

(d) Variations in the values of the replaceable bases over an area or down a profile entail variation in the moisture of hydration for constant moisture-content and this may again lead to variations in the value of cohesion.

(e) To a smaller extent, changes in atmospheric pressure and the pressure of the soil air also effect the cohesion.

(f) The shearing resistance of a soil falls off when the normal load reaches the failure load, in the case of sands, and the range of loading between the safe bearing load and the failure load in the case of cohesive soils. This is due to the formation or partial formation of shear cones or wedges resulting, by finite or infinitesimal movement, in a loss of apparent or true cohesion.

It is thus clear that cohesion is not by any means a constant factor for any site and to know the actual cohesion, which can be developed under any set of conditions, it is necessary to know, or to be able to estimate, the effect on it of the other factors involved.

3 *Interconnection, between Friction and Cohesion.* Up to the time of Langtry Bell's famous, though ignored, research work [58] and, generally speaking, even up to the present time, most earth pressure computations are based on the knowledge of some form of the angle of friction. The resistance of a retaining wall to sliding is usually calculated, in part, on the coefficient of friction between the wall base and the soil below. Modern research shows that for clays, especially for fat clays, this conception is untenable unless, as mentioned in Section 1 above, friction and cohesion are held to be closely related and, in some instances, practically synonimous.

A carefully conducted shear test on clay elucidates this contention. The graph of shearing resistance takes the form shown in Fig. (17), where the angle of internal 'ϕ' friction may be very small, and is often below 5 degrees and rarely exceeds 10 degrees. It has been more recently discovered that the true angle of internal friction required for the

determination of the "basic line of rupture" is even smaller than this measured angle [59].

As the tangent of five degrees is 0 087, the frictional resistance to sliding is very small although such a clay bank might well stand vertically and a table of natural slopes might, for such a clay, give an angle of fortyfive degrees

Discussed physically the reason becomes clear. Each unit or micelle of clay may be conceived as being surrounded by a sheath, or film, of water or moisture which is believed to vary in consistancy from free water—on the outside—to solid water-or water of hydration—on the inner side. The thickness of this film, especially that portion classified as free water, varies with the moisture-content of the clay and such viscosity altering functions as temperature. The result is that under normal moisture-contents one clay unit or *micelle* does not necessarily touch the adjoining one—only the water-films being in contact—and hence in shear the action is a sliding of molecular water-films over each other rather than a frictional action of one solid particle over another It is this breaking and making of contact between molecular films of water which gives rise to the viscous properties or the plasticity of clay. The property measured in the shear test is the sliding resistance of the moisture films with, perhaps, a small amount of true friction

The effective angle of internal friction is therefore small for cohesive, especially fat clays, and the measurement is one of cohesion rather than friction although the argument is reversible. (See Terzaghi's definition of cohesion, below).

The shearing resistance of a fat clay is mainly its cohesion, i e. its shearing value at zero normal load. Some Authorities[60] go further than this and state that the shearing value of the cohesion is the only safe value to take for such days as it represents the yield value of the clay soil This is really obvious, from the physical interpretation above, for to mobilize the small frictional resistance motion or yield is essential and such a motion once started introduces the plastic properties of the soil which might be fatal in a wall foundation.

The following definitions of cohesion, true and apparent, are given by Terzaghi and are taken from a series of articles on the 'Principles of Soil Mechanics' by Dr C. Terzaghi published in the Engineering News Record, 1925, in particular, Part 1—Phenomena of Cohesion of Clay, November 5.

"Thus all phenomena associated with the cohesion of clays are capable of being explained by the single factor of surface tension. Cohesion is the internal frictional resistance produced by the capillary pressure. As the cause of the capillary pressure—the surface tension of the capillary water—is an external one merely acting on the surface of the clay, the cohesion due to the capillary pressure may be called the 'apparent cohesion', in opposition to the 'true cohesion' produced by initial friction[4]. As the initial friction was found to amount to

not more than 20g./cm., the true cohesion is very small compared with the apparent cohesion".

"*Note—The term 'initial friction' as used by the author denotes the shearing strength of clay when not under pressure, either external or capillary. Extended investigation of initial friction showed it to be far too small in amount to account for any of the properties commonly grouped under the general term "cohesion of clay". The internal friction which acts in the interior of the clay subjected to either load or capillary pressure is the sum of (1) initial friction, which is practically independent of the intensity of pressure, and (2) the frictional resistance set up by the pressure, which is proportional to the intensity of the pressure Even at small pressures, however, the first item is almost negligible compared to the second".

B. Hydrostatic Uplift effect on Shearing Resistance.

This is a very important point and several very important and fundamental properties resulting from hydrostatic uplift have recently been examined and verified by experiment

Firstly, it has been shown that, under suitable conditions, hydrostatic uplift may be effective in any kind of soil whether cohesionless or cohesive.[61]

Secondly, that under hydrostatic conditions, the hydrostatic pressure in a saturated soil, is equal in all directions and is fully active.[59,61]

Thirdly, that part of the external load is carried by the soil particles and part by the water under hydrostatic pressure [59]

i. e. $L = l_s + l_w$, where L is the total external load,

l_s is the load carried by the soil particles and

l_w is the load carried by the hydrostatic head.

When considering normal loads for frictional resistance to shear, the same formula is applicable, and

$N = n_s + n_w = n_s + l_w$

i. e. the effective load carried by the soil is

$(N - l_w)$.

The frictional resistance to shear is thus made up of two parts

$f(N - l_w)$ and $f(l_w)$.

It has been proved that the fraction of the resistance $f(l_w)$, i. e. due to the part of the load carried by the water, has practically no bearing on the total frictional resistance and may, in fact, be taken to be zero. This also follows as a corollary from Terzaghi's definitions given above.

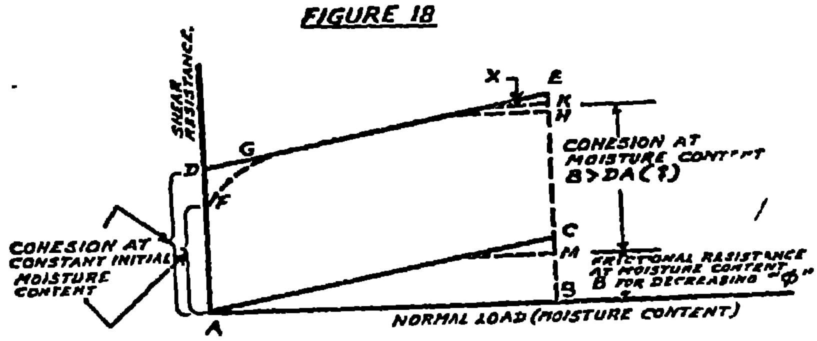
The component $f(N - l_w)$ is Coulomb's '$n.\tan\phi$' in his equation shear resistance.

$$T = C + n. \tan\phi.$$

As regards 'ϕ', experiment seems to indicate that with increase in pressure the angle slightly decreases, presumably due to the more active part played by the films on compaction.

The results of the above are shown diagramatically in Fig. 18 on the assumption that for each point on each curve the 'initial' moisture content of the soil is constant.

FIGURE 18



Legend to accompany Fig. (18).

AC = line of constantly increasing frictional resistance for constant value of ϕ.

DE = line of constant cohesion superimposed on AC.

AM = line of frictional resistance for decreasing value of ϕ.

DH = line of constant cohesion superimposed on frictional resistance for decreasing value of ϕ.

DK = line of increasing cohesion superimposed on frictional resistance AM for decreasing value of ϕ.

FG = Non-uniformity sometimes found for low range of loading due to looseness at initial state.

The tangent at any point 'X' of the shear resistance curve, DK, gives the true angle of internal friction but it does not represent the ϕ of Coulomb's equation neither does it represent the angle of rupture for cohesive soils[59]. The angle ϕ at X is less than the angle ϕ_x of the top curve and the difference is said to be in many cases very important, though it is admitted that the difference in shearing resistance represented by the two curves seldom exceeds 5 per cent[59].

In the examples, discussed by Terzaghi for fine grained cohesionless soils, he shows that[62] :—

(a) If the backfil of a retaining wall be fully saturated and there is no drainage then the resultant pressure on the wall exceeds that due to a water back-fill.

(b) That during a rainstorm, a wall with a back filter retaining a soil whose permeability is medium and is less than the rate of rainfall and of the order of 1×10^{-4} cms./sec. and whose compressibility is low, the resultant pressure on the wall will be greater than it is during fine weather. In the particular cases of highly permeable clean sands and highly compressible feebly permeable soils, the continuous flow does not occur and no flow hydrostatic pressure results.

(c) A suitably placed inclined back-filter and proper drainage eliminates the hydrostatic pressure produced by the flow of water.

The above comparisons were based on :—

(a) The effect of rain on the unit weight of the back-fill is negligible

(b) The wall will yield sufficiently to mobilize the full frictional resistance along all faces of the shear wedge.

C. Dilatancy of Saturated Fine Sands.

There is another aspect of shear and hydrostatic pressure which requires consideration especially in the design of embankments, dams etc.

Whereas a fine sand compacted to maximum density increases in volume under shear, a loose fine sand decreases in volume[63]. Hence if the loose fine sand be saturated, the effect of shear is to expel the moisture but as this cannot, normally, occur immediately, part of the load is transferred from the sand particles to the water, as considered in B above, and its shearing resistance is decreased This reduction is often sufficient to cause failure of the embankment etc. Fine sand should therefore be densified by mechanical means or by flooding.

It has been observed by several authorities that even clays decrease in volume under shear so that it is for consideration if all cases of failure by shear are not a form of thixotrophy.

D. Use of Cohesion and Friction in Design

It is thus clear that Cohesion and Friction are very closely allied. In designing a wall against sliding it is, in a way, correct to say that the shearing value of the soil is the criterion but except for granular materials it is often incorrect to base this on :—

$$f(N - I_w) \text{ or } n. \tan\phi$$

where 'ϕ' is a value assumed and often assumed to be very much greater than is justifiable The correct value, in such cases, should be

$$c_w$$

where c_w is the cohesion at the maximum moisture-content to which the soil be subjected 'in situ'. The above is, of course, based on the assumption that the foundation is rough and shear is along a plane just inside the foundation soil and not along a perfectly smooth plane of separation between the two materials.

Needless to say, the correct values of the internal angle of friction and of the cohesion can only be determined by experiment.

CHAPTER 20.

MECHANICAL ANALYSES.

Definition—Mechanical Analyses, is, in general, a mechanical separation of the soil sample in to a series of fractions whose limits are largely, but not wholly, empirical. It is an arbitrary method for the comparison of soils. The reason for the degree of arbitrariness is clear when it is realised that a normal matured soil consists of a more or less continuous and gradual change in particle size from the largest down to the smallest. Some limits are necessary to distinguish fine gravel from coarse sand, fine sand from silt and silt from clay. There is, in general, for matured soils no sudden change and the obvious method for distinguishing the fractions is to demarcate arbitrary boundaries which serve simplicity, a separation of mechanical properties and practical methods.

In addition to the arbitrariness of the fraction limits the results obtained depend upon the method or sub-method employed for the determination of these fractions. Pure screening—a difficult process for the lower limits—gives one result, but it is obvious that this result is not always a true one. Before screening, the sample must be dried and in drying the natural soil elements and the moisture - films may, and usually do, cause the finer particles to form aggregates and hence the finer fractions are not truly represented by the results. Grinding is useful to break down the larger of these aggregates but grinding may damage the larger particles and may not break down the smaller aggregates. To overcome these difficulties and to obtain segregation the method is to obtain complete dispersion in some suitable alkaline or deflocculating medium. A common method is to remove the cementicious co[illegible]ts—chiefly humus and carbonates—by boiling with 6 per cent hy[illegible]gen peroxide* to destroy the humus and then treating with 0.2N [illegible]drochloric acid which dissolves the carbonates and prevents them [illegible] acting as a flocculant. The sample is then washed to remove the soluble bases and final dispersion is obtained by well shaking with 0.008N sodium hydroxide. A better method applicable to [illegible] oils is to omit the acid pretreatment and disperse in sodium [illegible]ate.[64]

The coarser fractions down to 0.2 m.m. are first removed by sieving and the finer fractions are determined from the prepared sample by the pipette or other approved method.

In using the results of mechanical analyses it is therefore necessary to know:–

(a) The fractional limits, or the System adopted, and

*Authorities differ over this percentage as it will presumably vary with the average humus content of the soils under examination.

(b) The particular method used in the determination of the fractional values.

The actual method used for a series of tests and for comparison is not so very important for average soils so long as the method used is consistent. If the method be changed, the results are not necessarily comparable especially in the important clay and colloidal fractions.

As an illustration of the importance of (b) an unusual sample from an Eastern Soil Group was analysed in Europe in accordance with the custom of that laboratory, which had perfected a system suitable for the soil groups of its locality, i.e. by dispersion in 0.01 sodium oxalate with no pretreatment The analysis by this method gave –

		Per cent.
Sand	..	4 1
Fine sand	..	14 7
Silt		41.7
Clay	..	39 5
(Colloidal clay		16.5)

but the colloidal clay values did not correspond to the anticipated values as determined from the correlation graphs connecting the colloidal clay content with the soil constants A sample was then pretreated with 6 per cent hydrogen peroxide and N/5 hydrochloric acid before dispersion with the result that the analysis changed to –

		Per cent
Sand	..	2 0
Fine sand	..	27 3
Silt	..	22 7
Clay	..	48 0
(Colloidal clay		39 7)

showing a very considerable difference and giving compatible results

To complete the discussion it must be remembered that the Soi Constants, including the mechanical analyses, are considerably affecte by the nature of the clay[65]. In nature the clay complexes, or micelles have adsorbed on their surfaces *ionised cations* of the soil bases i various proportions giving rise to such clays as H-clay, *Ca*-clay *Na*-clay or *Mg*-clay etc In some cases they are more or less saturate with the predominant *cation*, whilst in others the division is not sc complete. Actually, *in situ*, over any particular area the ratios of the exchangeable bases may vary and also the total exchange capacity o the soil. These variations are reflected in the soil properties For the purpose of standardification, and hence comparison, the method adopte solves this problem by changing the given sample to a hydrogen, sodium or ammonium clay according to the method and dispersing agent used The method applied again becomes important in using the results. The clay and colloidal clay fractions vary with the dispersing medium, i.e. with the nature of the clay produced by the medium and process and hence although the results are useful for comparison in any

particular soil group they do not necessarily represent the exact 'in situ' values.

The following variations, representing perhaps a fairly extreme case, for an average of 90 per cent base saturation, are given by Winterkorn[31]:—

	Natural Clay		Na-clay		Ca-clay		Al-clay		H-clay	
	C%	Col C%	C%	Col. C%	C%	Col C%	C%	Col. C%	C%	Col. C%
Putnam Clay	33%	12%	47%	30%	30%	13%	29%	18%	31%	18%

(where C = percentage clay: Col. C = percentage of colloidal clay).

with the following variations in the Soil Constants:—

Plasticity Index	17	32	21	15	16
Shrinkage Limit	15	16	15	18	18

Limits of the Soil Fractions.

The most useful system to the engineer is that adopted by the Bureau of Public Roads as described in Chapter 1 under Engineering Classification.

One simplification has already been referred to, another is the fine sand—silt limits are sometimes changed to

Fine sand 0.42 — 0.07 m.m.

Silt 0.07 — 0.005 m.m as the dividing sieve, No. 200, though not differing greatly from the No. 270 sieve is much easier to use and it is on the No. 200 sieve screened material that the physical tests for the soil binder material are performed when it is desired to examine the properties of these active constituents.

The results of mechanical analysis are best examined by plotting the accumulation-grain size curves on semi-log paper. The curves are then independent of the grain size system used.

CHAPTER 21

THE SURFACE TENSION THEORY IN SHRINKAGE, SWELLING AND CONSOLIDATION—HYSTERESIS.

In Charles Terzaghi's explanation of the phenomenon of Shrinkage[66] 1925—he likened the process to the confined consolidation test on a saturated sample with provision for the free escape of expelled water. When a saturated sample is loaded it decreases in volume by an amount equal to the volume of the water expelled. The decrease in volume is equivalent to a shrinkage where the shrinkage is due to an expulsion of water brought about by an external load.

Similarly, if a loaded saturated sample in contact with water at atmospheric pressure is unloaded the soil will swell and take up a volume of water equal to its increase in volume. This is equivalent to the swelling of an air free soil sample in the presence of water.

In the loading and unloading tests the water of saturation is, when equilibrium is established, at atmospheric pressure, there is no hydrostatic head and the load is carried by the soil. Before the condition of equilibrium be reached, in the example of the loading test on a cohesive soil, the increase in load is initially carried wholly by the water. This load sets up a positive hydrostatic pressure in the centre of the sample inducing expulsion of water with a decrease in pore space. In the unloading test, it will be shown, the elastic properties of the soil induce a negative hydrostatic, or suction head, at the surface of the sample producing an intake of moisture with attendant increase in pore space.

Experiment shows that if a loaded saturated sample in equilibrium is cut off from its free water supply, unloaded and evaporation prevented then there is no change in volume. Hence from the loading tests, which show that a change in volume must be accompanied by a change in load, the load to which this particular sample was originally subjected must be replaced by some loading of a different nature.

According to the capillary theory of moisture movement, the capillary rise from a free water surface, i.e. one at atmospheric pressure, is given by:—

$h = \frac{4.T.\cos\alpha}{d\rho.g}$, where T = surface tension of water,

α = angle between the meniscus and the walls of the tube,

d = diameter of the capillary tube, and

ρ = density of the water

The movement up to the capillary tube to this height 'h' is caused by the surface tension force and equilibrium is established when the surface tension force is balanced by the force of gravity acting on the head of water in the capillary tube. The water in the capillary tube is in tension, its amount varying with the height from the free surface. Analysis shows its maximum value to be 4T/d

If water enters a capillary tube from above and the free supply is suddenly cut off several alternatives can occur. If the capillary tube be of uniform diameter and the temperature be constant the water will sink under gravity, the surface tension forces at both ends being equal, and discharge from the bottom of the tube until the height in the tube is equal to the capillary head if the bottom of the tube be inserted in free water. If the temperature of the water at the top of the tube be decreased the surface tension of the water at the upper end is increased and a condition of equilibrium, as a suspended capillary, can arise. If the capillary tube be tapered with its widest section downwards the total tension force at the lower end will decrease so that a taper can be found at which the suspended capillary is again in equilibrium, i.e. when,

$4\,T.\,(1/d_1 - 1/d_2) = g.\rho.\,h.$ where 'h' is the height of the suspended capillary.

The important factor about these various conditions is that in each case the capillary water, whether from a free surface or as a suspended capillary, is in tension.

Since an active force of this nature calls for a reaction, equal and opposite, it follows that the tension forces in the water must be accompanied by compression forces in the capillary tubes themselves, transmitted from the water to the tube through the adhesion between the meniscus film and the tube. This is the reason why shrinkage and compression are equivalent and it is this tensile force in the capillary water which takes the place of the external load when the sample is allowed to shrink by evaporation.

Shrinkage.

Supposing all the sides of a smallish test specimen of soil are surrounded with water at atmospheric pressure If the soil be considered to be made up of a large number of capillary tubes there will be no menisci and hence no pressure in the soil If the free surrounding water be gradually evaporated until it is about to disappear menisci will be about to form. Further evaporation will cause their formation and a compressive force will be gradually induced in the soil. Loss of water and compression are accompanied by contraction and contraction causes a decrease in pore space or in the size of the capillaries. As the capillaries decrease in size so the tension forces in the capillary water increase.

In the consolidation test the applied force is an external one, there is no capillary tension. A decrease in volume is accompanied by expulsion of water and a decrease in the diameter of the capillaries. In the shrinkage test the applied force is an internal one of capillary tension produced by evaporation,

A typical shrinkage curve is shown in Figure (19).

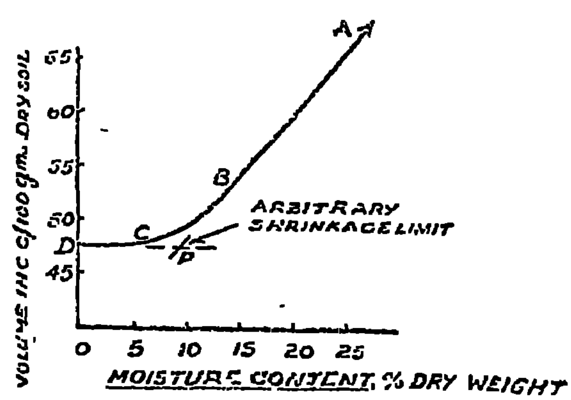


FIGURE 19.

For the range AB, where 'A' can be taken to be the *Liquid limit* and 'B' the *plastic limit* (approximately), a decrease in moisture content is equal to the change in volume or decrease in capillary volume. This

range represents the maximum range over which the consolidation test can be applied. From 'B' to 'C', a new phenomenon is introduced by stress limits By the time 'B' is reached most of the capillary water has evaporated and the soil is under very considerable pressure. Further the vesicular moisture held in the cellular colloidal structure is also decreasing and disappearing in evaporation with the remainder of the capillary moisture. Between B and C the colloidal particles are in a very high state of compression and their resistance to further shrinkage has almost reached its maximum. A point is finally reached when the colloidal structure fractures under stress This is accompanied by a recession of the remaining capillary water to the centre of the specimen with a sudden change in colour accompanying the entry of air This point is known as the *shrinkage limit*. From 'B' to the *shrinkage limit* the strength of the colloidal structure is being mobilized to resist further contraction. In this range changes in moisture content are accompanied by a decreasing change in volume until the *shrinkage limit* is reached after which no change in volume, or only a very small change, accompanies any change in moisture content now gel moisture. Any rewetting leads to increased volume due to the presence of air which has entered the soil.

From the above it is clear that the analogy between shrinkage and consolidation only holds down to the moisture content corresponding approximately to the *shrinkage limit* but as the shrinkage limit corresponds to pressures outside those attainable with the consolidation apparatus it is of no practical importance

Shrinkage curves plotted as shown in Figure 19 have some interesting properties. If AB be extended to cut the vertical axis in E then OE represents the volume of the hypothetically compacted soil, i e., with no voids. Since this value is also equal to 100/sp gr. the line EA will be constant for any particular completely saturated soil. This means that if the apparent density of any specimen of that soil, in any structural condition, be determined then the *shrinkage limit* may be read off from the graph No fresh determinations are necessary The shrinkage limit thus becomes a measure of the structure.

The length DE = DP gives the pore space so that the shrinkage *limit* is also numerically equal to the pore space

The surface area of the soil particles is often considered to be a measure of the hygroscopicity but if the surface area of the pore space be considered to represent the hygroscopicity, which seems an equally valid assumption, under conditions of compaction and dryness, then the *shrinkage limit* becomes a measure of the hygroscopicity. If this be true, however, then the hygroscopicity must vary with the degree of compaction.

A further property of this curve is that the volume of the voids, when dry, is numerically equal to the moisture content percentage necessary to fill the voids. If all air were extracted and the soil were granular the voids would be filled by the time the *shrinkage limit* was reached, i.e. if there were no swelling Actually a little hydration swelling occurs so that a somewhat different amount of water is required. From Schofield's work it would not be expected that the quantity required, during drying and wetting, to fill the voids would be the same. The curves given by Russell [11] show a higher *shrinkage limit* for the rewetting curve,

though Haines' [75] curves indicate a lowering of the shrinkage limit on wetting. Haines states that as the moisture content does not decrease below the shrinkage limit the shrinkage curve is reversible. It is only when air enters that the wetting and drying curves differ.

As the density of clay soil particles will vary with the hydratation and *osmotic* hydration it appears impossible to calculate the amount of water necessary to fill the voids from details of the voids ratios or densities of dry samples. Wetting causes an increase in voids ratio which is more apparent than real as some of the water determining the voids ratio has entered into chemical combination with the soil.

Theory is not very clear on this point Whereas the generally accepted belief developed by Comber[77] is that the colloidal clay exists as a coating around the coarser particles there is the older theory of Tompany[78] that the colloidal material exists as a ramification throughout the mass. The former means an increase in the volume of pores during swelling, the latter, a decrease.

Russell and Gupta [79] said "A soil swells on imbibing water and this swelling will probably alter the pore-space geometry of the fine pores by reducing their volume" Keen [80], who apparently is a supporter of the former theory, seemed to agree with Hardy [81] that for siliceous clays the average pore diameter decreases during the swelling of the colloidal material.

Limitations of the Surface Tension Formula. To use this formula values must be given to T, d, $\propto$, ρ and d. The value of 'T' remains constant with constant temperature. The value of '$\propto$', usually assumed to be zero, is not necessarily so for soils especially when salts are present. The density of the liquid remains constant for the range AB of the shrinkage curve but for lower moisture contents the tremendous pressures to which it is subjected cause an increase in density.

The diameter 'd' of the capillaries has two bearings on soil calculations. For uniform capillaries of very small diameter, indicative of high pressures, the water apparently changes into water vapour which moves similarly to capillary moisture but at a very much retarded rate. This is an important point in the study of moisture movements.

The second bearing of the capillary diameter is that in soils the capillary tubes are not of uniform diameter; they are approximately of the shape shown in the two-dimensioned Figure 20.

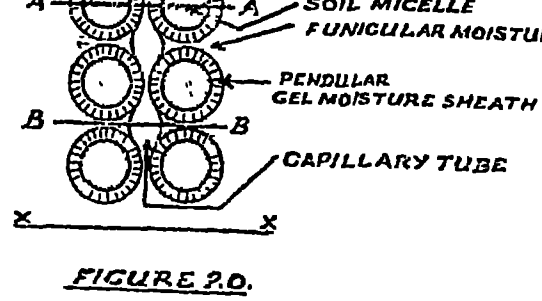


FIGURE 20.

The capillary head for a soil, according to the surface tension formula, being wetted from a level XX is determined by some head h_1 represented by some wide section BB whereas for wetting conditions downward from some surface YY the height h_2 will be determined by some neck AA. That is the capillary head varies with whether the movement is upwards or downwards. A similar argument was held to apply to conditions of drying and wetting from any given level.

The above complications introduced into the surface-tension theory induced Dr R. Kenworthy-Schofield[68], of the Rothamsted Experimental Station, to formulate a new theory independent of any variables. Instead of measuring the capillary head by the surface tension method he measures the internal tension of the moisture as the height in centimeters of a column of water which corresponds to the suction head necessary to remove the remaining moisture. The measurement of his suction head, or capillary potential, is based on free energy relationships and hence is independent of the mechanism. He expresses his head values by what he has termed pF values which are merely logarithms of the suction head. The actual values are determined from such tests as the C.M.E., vapour pressure, freezing point and vacuum suction.

The results are of particular interest to engineers as they appear to represent the absolute case of the consolidation curve.

A comparison of the two general curves, given in Figure 21, is interesting.

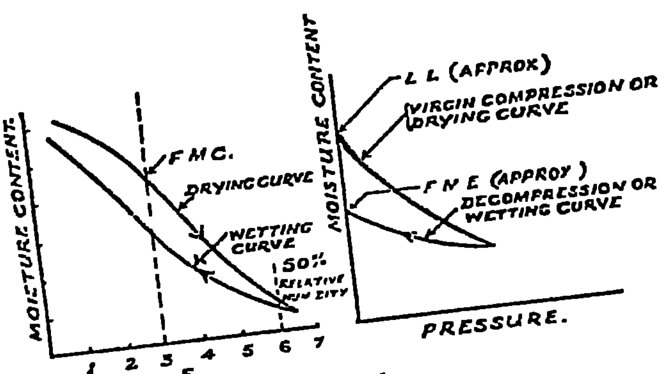


FIGURE 21

Note that in both curves there is hysteresis.

The consolidation results are plotted to a scale relative to atmospheric pressure so that to convert the Moisture—pF diagram to the Moisture—Content—Pressure diagram an axis passing through pF =3 must be drawn for the purpose of comparison.

The agricultural Field Moisture Content or Equivalent is determined and is approximately represented by pF =3 or pressure on the consolidation curve. In the engineering test the mined on a wetting basis and hence occurs approximately

where the decompression curve cuts the moisture content axis. The agricultural F M C. therefore corresponds approximately with the *Liquid Limit* which is, incidentally, not determined specifically on a drying or wetting basis.

The C.M.E., determined agriculturally and engineeringly on a drying basis, should correspond.

Though the engineering consolidation test apparatus is restricted, by virtue of the magnitude of the forces involved, to moisture contents above the *plastic limit*, the pF curve gives the pressure required to reduce the moisture content right down to zero which approximately corresponds to a water head of 10^7 cms. or a head some ten times the height of Mount Everest. This value apparently applies to all clays.

Terzaghi,[66] 1925, calculated the capillary pressure of two clays as 171 and 339 tons/sq foot at their *shrinkage limit*. These pressures correspond to a pF of 5 23 and 5.53 against Schofield's pF of 6 for all clays at 50 per cent relative humidity.

Hysteresis. The reason for the hysteresis loops in the drying and wetting curves is not yet clear. From an engineering and modern physical point of view it seems to be bound up with particle rearrangements. The older physical conception of the lento-capillary point, or the engineering F M.E., seems to offer some idea of a solution. It was found in the early days that if a limited quantity of water was added to a soil it would only moisten the soil to a limited depth or height. To this depth or height the moisture content remained fairly constant at the F.M E. but beyond there was a sharp decrease. Below or above this level the capillary flow was inappreciable. There was however still a moisture flow but a very slow one. In this stage moisture apparently moves in a film or vapour form and its magnitude and rate is controlled by corresponding laws.

According to Schofield, the phenomenon is repeated in the statement that a dry soil placed in contact with a wet soil will absorb moisture until the drying 'pF' of the wet soil equals the wetting 'pF' of the dry soil being wetted, when capillary equilibrium is reached although there may be an abrupt change in moisture content at this point.

In the decompression test or wetting test the moisture content is already below the F.M.E or lento-capillary head and hence any natural movement of moisture is necessarily slower than the movement produced by artificial means on drying. It is only when the pressure equals zero, or atmospheric pressure, that the lento-capillary head condition is reached. In the drying test on a virgin curve, on the other hand, the soil is artificially persuaded to take up moisture equal to the *Liquid Limit*. It is not a natural condition.

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83 "The Colloidal Constituents of California Soils", W. P. Kelley, W. H Dore, A. O. Woodford and S. M. Brown, S. S. Vol. 48.

84. "Minerals present in Soil Colloids—1, Description and Methods for Identification", S B Hendricks and L T Alexander, "II, Estimation in some Representative Soils", L T. Alexander, S B. Hendricks and R. H. Nelson.

85. "The Science of Foundations—its Present and Future", C. Terzaghi, Trans of Americ. Soc of C E, Vol. 83, 1929.

Mr. Mahabir Prasad (Chairman) called upon Mr. Woolterton to introduce his paper. The above paper was taken as read.

Mr. S. R Mehra introducing the paper, on behalf of the author, read the following note :—

Mr. President and Gentlemen,

(1) I wish to express my regret at not being able to be present at this meeting and especially because I have been for many years (even before the paper was written some three years ago) very anxious for the opportunity of verbally stressing to Engineers the great help to be had, in the study of Soil problems, from the literature of the Agriculturalist, soil physicist, soil chemist, and in general, of the pedologist and from personal contact with these authorities. For the information of Soil Experimenters, I would add that I have always received the fullest co-operation from soil specialists not only in Burma but in India and America. Should an Engineer ever be desirous of obtaining information and or advice in any particular Soil problem, I would suggest that his first step should be to approach such authorities In particular, I would refer to Dr. Hans F. Winterkorn of Missouree, I believe, but the University can be verified from issues of Public Roads He is specially capable of answering questions on Soil problems pertaining to the chemical side and is an authority on Sodium and Magnesium clays. You will find him very helpful and willing to co-operate in any way he is able.

I also wish to thank Mr S R. Mehra who has so kindly consented to sponsor this paper, in my absence on leave to fit me (amongst others) for our rather strenuous future operations in Burma Should anyone be desirous of corresponding with me then my address may be obtained from the Secretary I shall be very pleased to help in whatever way I can.

(2) There may be some present this evening who are justifiably asking themselves "of what use is all this rather foreign information?" I will give two examples of its value—a general and a particular example.

(3) (a) In a highly industrialised country there has been accumulated, through the ages, a very considerable and valuable experience which is available to the designer and anyone undertaking an enquiry, whether in respect of some proposal or in respect of some failure.

This experience will answer most questions, and only occasionally—but nevertheless occasionally—is resource to more fundamental information necessary. But please do not be under the impression that experience—vast as it may be - will answer every problem because it will not. I can call to mind the mechanical and pedological example of a famous London Collapse of recent years and the more recent mysterious movements in Buildings, in certain parts of London, for which experience, at the time, had no answer

Supposing, however, there is no experience to guide? Supposing an important structure is to be erected in an area far remote from any experience of value. What then? A study of that area by a trained pedologist, aided by a Soil Map, will, in a very short time, produce the life story of

the soil—its past and present A living account of its general properties of cohesion, plasticity, permeability, moisture movements etc, something very much more understandable than those arbitrary and dead values given by the Consistency Tests or by the somewhat unrealistic compression, shear and cohesion tests, useful as they may be as a basis for design

(b) I wish now to explain how this contribution came to be written When I first arrived in Mandalay, Burma, I was handed over a number of badly cracked and even a few condemned buildings which, from the number, extent and width of cracks, were very disconcerting Shortly afterwards I was asked to advise on the rebuilding of a privately owned office This building was luckily a very simple one—a single-storeyed, rectangular brick building with a steel trussed roof The cracks were all in the long walls and roughly radiated out from two focal points. These cracks did not point to bad workmanship but to something different. Plinth levels indicated a very unusual form of deflection curve which agreed with some of the cracks but not all To check against overloading the soil, an analysis showed that the transmitted pressure was ridiculously low at only one quarter of a ton per square foot. It was impossible to consider this too high when safe existing and test loads gave two tons with maximum permissible loading of approximately six tons per sq foot.

Further study of the cracks suggested the present plinth curve was not the original curve and that the building had been subjected to a peculiar action. All this was contrary to one's engineering training and no explanation could be obtained from any engineering reference book or, other than general and rather meaningless suggestions, from local experience.

(c) I had intended to give further information on this problem but time does not now permit me Some of you who have similar problems will be interested to know that the Report on this Investigation will be published under Soil Movements as soon as paper becomes available

(d) In brief a complete pedological investigation was undertaken down to changes in moisture content and to X-Ray Analysis of Soil Sample

The ultimate finding was that cracking was caused by, relatively, rapidly alternating differential horizontal and vertical drying and wetting in an *ultimate* raising or lowering of the central portion of the structure to a more or less constant level, where raising occurred when the building was constructed on a very dry soil The general dome-shaped curve—not a dish curve—develop with flexibility and design into a sinusoidal curve There was evidence that some of the now dome-shaped curves were initially of the usual dish-shape

And the reason for all this was that the soil was not a sodium-clay as supposed but a sodium-magnesium clay in which the magnesium caused and augmented the deleterious property of swelling *but* in other ways acted as a calcium clay i e. permitted permeability and hence rapid changes in volume corresponding to changes in moisture content represented by the limits of the residual shrinkage range Further, the swelling properties

involved a swelling pressure of about 1½ tons per square foot which meant not only in theory but in verified practice that unless the loading was greater than 1½ tons per square foot, the soil loaded the building instead of the opposite. Hence also the reverse deflection curve.

4. I had meant to enlarge on the value of the shrinkage curve but must be content now with noting that it is of considerable value studied with the pressure-voids curve and the knowledge of yearly moisture changes. Though usually determined for a remoulded sample it is easy to convert the curve to suit "in situ" conditions when the "in situ" apparent density be known. It is then that one begins to understand what is happening.

5 In conclusion I wish to thank you, Gentlemen, for taking an interest in this paper. My main reference above has unfortunately, perhaps, been supplied by a building problem but believe me the Pedological approach is of even greater value when considering a Soil Problem connected with Road construction.

I had meant to refer to the Lahore Road Tests but again am unable to do so at length. I should like however to record my agreeable impression that the experiments were a great success no matter what they looked like or however many sections had failed, for what to me were very obvious reasons. To make the best designs 100 per cent. useful, all that is, in general, necessary is some moisture stabilisation or some *equivalent* treatment. I hope this work, in the interest of Soil Mechanics, will be permitted to be continued on organised lines.

Mr. J. Bhatt (Bhavnagar):—

We are indebted to Mr. Woolterton for giving us an excellent compilation on the " Fundamentals of Soil Mechanics ". It fulfils a great need for reference on the subject as, little or no data, is available in one compilation on the subject. In this connection, let me recall, the remarks I made at the Hyderabad Conference (Discussion on paper " F ", page 13 (f), I. R. C. Proceedings, Vol. 4) regarding the need for the study of soil characteristics to improve the condition of Agricultural roads, and of correlating the knowledge gained in the Laboratory to actual practice of road construction.

Soil Mechanics--though comparatively of recent origin—is well established as a science, and the results are applied in practice with profit to " Foundation Engineering " for predetermination of settlement and bearing capacities; to " Railway Engineering " for earthwork and stability of slopes; to " Irrigation and Water Power Engineering" for investigation of permeability, see page and piping etc. There is no reason, why, therefore, the fundamentals of this science could not be utilized with equal or more profit for Highway Engineering by the Road Engineer.

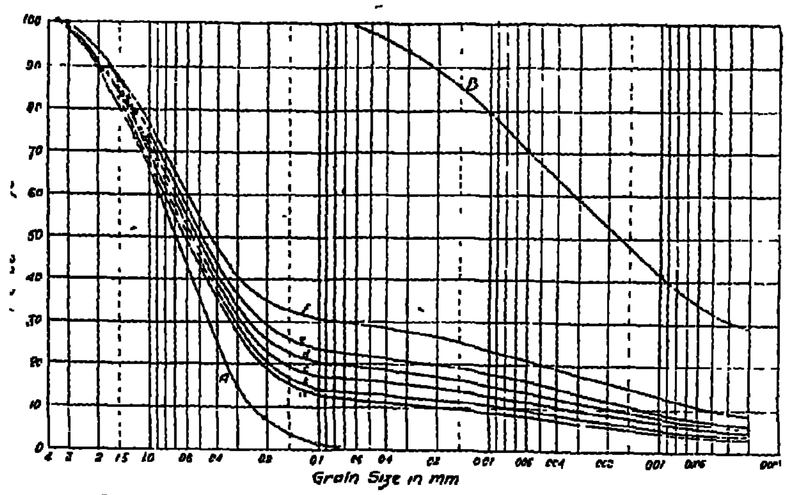
Mr. Woolterton has mentioned in the introduction that the knowledge of the science of soil mechanics in some instances is in the stage of " hotly contested " modern views. Let me assure you that this is not so. The knowledge of the fundamentals, and the results, as applied in practice, are " stabilized" enough to permit us carrying on experiments with "stabilization" of soil.

Gentlemen, you have seen this morning experiments on soil stabilization, and I am happy to greet Mr Mehra as a comrade-in-arms, working in the same direction I overheard a few remarks and questions, whether some 'rough and ready' means for field use, could not be devised to determine the proper percentage of admixture of soil and clay Well at the present stage, a laboratory for soil mechanics is essential to determine the composition, which would give best results Soil, that " Universal Cement ", is easy to obtain everywhere, but very difficult to comprehend For each area, the proportion of sand and clay, which gives best results, will vary and must be determined by laboratory methods It will be possible to devise simple Field-tests for correlation only after sufficient experience is gained in laboratory tests.

We are grateful to Sir Kenneth Mitchell for rightly emphasizing at length, in his presidential address, the need for improving Agricultural Roads As one trained in U S A I am, all out, for super highways to suit the modern traffic, but once the urban roads and suburban roads are treated—the National Highways, the Provincial Highways and the District roads will have to be dealt with. Having dealt with these, there still will remain, tens of thousands of miles, of agricultural roads between community and community , and also as a link between one community and the net work of district roads as envisaged (no village of accessibility is measured by the formula that no village of—say—thousand population and over should be more than—say—a mile or half a mile from a public road) by Sir Kenneth Mitchell in the National Scheme. The application of the knowledge of the fundamentals of the science of soil mechanics will come in very good stead here. Economy of maintenance is the essence, and these low-cost roads should be so designed as to have minimum of maintenance For this, laboratory tests are indicated. Will it be too much, therefore, to suggest, at this juncture, that the Government of India, under the supervision of some such central body as the Indian Roads Congress, immediately set up, a soil mechanics laboratory ? The provincial Government and leading Indian States may then follow the good example. The cost of such laboratories will be more than justified and comparatively small, in view of the millions, that would be saved in the construction and maintenance of low-cost roads.

Mr Woolterton carried out experiment with London Blue Clay Co-incidentally, I am responsible for carrying out similar tests on Boston Blue Clay, on the other side of the Atlantic, in the soil mechanics Laboratory of the Massachusetts Institute of Technology (Boston, U S A) We all know in a qualitative manner, that a soil mortar could be improved by mixing proper proportion of sand and clay, the quality mainly depending upon the proportion and the characteristics of the particular soil. My purpose this afternoon is to indicate that the optimum value of the soil in an admixture could also be determined in a quantitative manner. With that view in mind, I have carried out experiments at the Massachusetts Institute of Technology in co-ordination with the Georgia State Board of Highways (U.S.A) on materials actually used in Highways construction of Federal Aid projects, and suggested improvements in the admixture to be used in practice. The tests carried out in Laboratory were on percentage clay contents and grain-size distribution The determining tests were —(1) Compressive Strength Tests, (2) Shrinkage Test, (3) Atterberg's limit Tests, (4) Slaking Time Tests, (5) Shearing

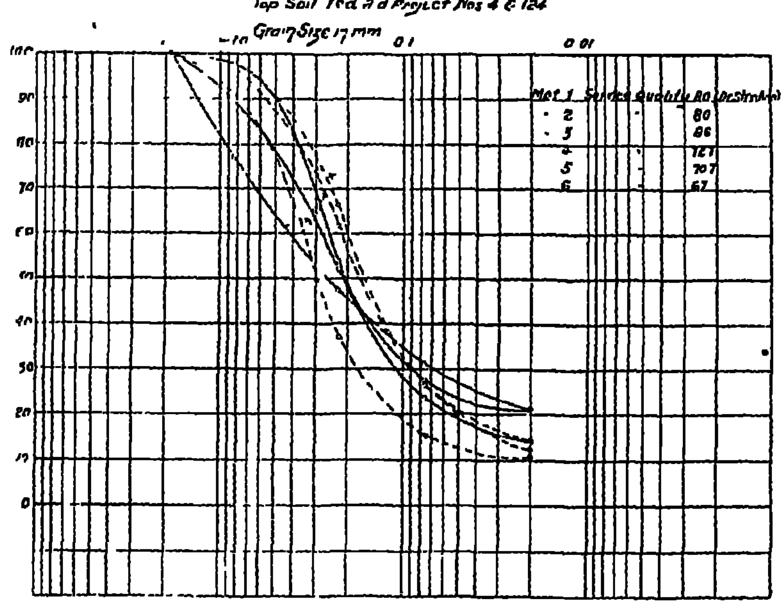
Resistance Tests. Let me explain just one of the tests on the graphs on page 298 (f) At one extremity we have the grain size distribution of Boston Blue Clay ; at the other, we have a similar curve for the cohesionless sand. In between, lie, the curves for various admixtures of different percentage of clay and sand : Similar curves could, also, be plotted for various admixtures of materials obtained in practice in the construction of low-cost roads Comparing these curves with an idealized curve, we can improve the percentage by pulling down the hump, or drawing up the sag, in a particular region, by altering the grain-size distribution i. e. the proportion of the soil. But this should perhaps suffice in indicating the line. Let the proper place for presentation of these results be in a Technical paper before the next Congress.



Curve "A"—MIT Concrete Sand
Curve "B"—Boston Blue Clay
PLL 21.4 LL 42.0

Curve "a" 12.4% Clay "B" + 87.6% Sand "A"
" "b" 14% " + 86% "
" "c" 16.8 " + 83.2% "
" "d" 20% " + 80% "
" "e" 23.2 " + 76.8%
"f" 30% " + 70%

Grain Size Distribution Diagram for Materials from Georgia
Top Soil Fed. Aid Project Nos 4 & 124



PAPER M-1943

ABSTRACT OF A *PAPER ON MASONRY ARCH BRIDGE OF 35 SPANS OF 60 FEET EACH ACROSS THE KRISHNA AT DEVOSAGAR — RAICHUR DISTRICT, H.E.H. THE NIZAMS DOMINIONS

BY

MD FARHATULLA, B Sc, C.E, A M I.E., *Executive Engineer, Special Works, Nizam's P.W D.*

1. The river Krishna traverses the Hyderabad State from West, to East, on the southern portion of the State, and forms the southern boundary between Hyderabad and Madras Province in the latter portion of its course. Raichur, headquarters of the district of the same name, and an important commercial town in the State, was isolated from Hyderabad during the major portion of the year, for want of a road bridge across the Krishna which crosses the Raichur Hyderabad Road at about 12 miles North of Raichur. This road is the main outlet of the State to Bangalore and Mysore on the South; Adoni and other important places of Madras on the East and Sholapur, Belgaum and other places of Bombay in the North and West. Construction of a bridge across the Krishna had been engaging the attention of the State for a long time along with the question of locating it either on the Kurnul Hyderabad Road near Alampur or on the Raichur Hyderabad Road at Devosagar It was finally decided to site the bridge at Devosagar and designs and estimates were prepared for a masonry arched bridge of 35 spans of 60 feet each. The bridge was completed in March 1942 at a cost of Rs. 11,38,715 (B S). The note below gives brief description of the design, Engineering difficulties met with during construction, and how these were overcome.

2. The river is a perennial stream, taking its source in the Western Ghats near Mahabaleshwar, and running in steep slopes through hilly country, in the upper reaches, till it enters the plains near Alampur. At the site of bridge near Devosagar, the catchment area works to 49500 sq. miles, with a calculated maximum discharge of nearly 0 45 million cusecs, using the formula** evolved by the late Chief Engineer of the State, Mr. Nawab Ali Nawaz Jung Bahadur. The mean velocity of the river is 8 8 feet per second, and works to 13 3 feet per second under the bridge, with an afflux of 1.23 feet The bed of the river at site is rocky, strewn with boulders. 4½ miles higher up, it is joined by Bhima, another big river. The water in the river rises suddenly and rapidly and floods are common even in the summer months.

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*Due to late receipt of the paper from the author and the pressure for space, the original paper has been abstracted It is available for reference in the I.R.C. office.

**$D = C\,M^{0.92 - 1/14 \log M}$, where C=1700 for hill catchments.

At Bridge site this works to 9,41,890 cusecs. As computed by a Special Survey from M F.L. at Railway bridge 2 miles higher up, this discharge works to 9,91,150 cusecs.

3. The bridge as now completed consists of 35 spans of 60 feet each, with piers, abutment piers and abutments of cutstone masonry, in surki mortar pointed with cement mortar Every 7th pier is made an abutment pier. Particulars of the bridge, regarding design and cost are furnished in appendices I and II

4 The following points deserve special mention

(a) The selection of the type of bridge was influenced by the following considerations :—

(i) availability of good granite stone, lime, sand and surki within short leads

(ii) availability of steel centerings for 60 ft spans, used for the construction of several similar bridges of the same span, in the state

(iii) experience gained in the erection of cutstone arch bridges, and the availability of technical personnel for supervision, and skilled workmen for dressing the cutstone work for masonry and voussoirs

(iv) Incidentally, the bridge work has, by using all local labour and material, afforded relief to the people in the locality during a period of acute famine.

(b) *Cofferdams.* Foundations were enclosed in cofferdams, which were formed by dumping blasted material and bed boulders on the upstream and downstream sides, till they were 2 ft above the water level The cofferdam was successfully staunched by the silt from the river bed, which was thrown on the upstream side The silt in suspension, on entering the boulder cofferdam got deposited in layers, because of the reduction in velocity, thus securing a watertight silt-boulder cofferdam. Some cofferdams were a quarter of a mile long. The top of the cofferdam was made sufficiently wide for a trolley line with a 4 ft margin on either side. (See sheet No 3.)

(c) *Dewatering—and plant.* Work was often disturbed even in the best working season by the river receiving floods in the months of March and April Arrangements were made to get daily rainfall and weather reports from Poona, to serve as a warning as to when a rise in the river could be expected, and the plants were allowed to work in the bed till the last moment

(d) An interesting feature when laying the arches was, that when the keying was in progress, vibrations were felt in the portions already keyed After the completion of the work, the arch as a whole got lifted by $\frac{1}{4}$ inch to $\frac{1}{2}$ inch above the laggings and further vibration ceased.

5. *General* High pilasters of finely dressed cutstone are provided at the road approaches With massive piers and abutments, and arch all of cutstone, and with well proportioned cutstone parapets, copings and pilasters, the bridge blends harmoniously with the surrounding hilly country with rockstrewn river bed and presents a majestic appearance.

APPENDIX I.

1. Piers.	7½ ft. thick at Springing with a batter of 1 in 24. Maximum Height 44·5 ft.
2. Abutment Piers.	17 ft. thick at springing with a batter of 1 in 12
3 Abutments.	12 ft. thick at springing with a front batter of 1 in 24 of and a rear batter of 1 in. 5.
4. Cutwaters.	Triangular, with a subtended angle of about 80°, formed with arcs of radii equal to ¾th pier width and centres at ¾th points of the same.
5. Foundations.	Taken to hard rock, rocky murram, or fissured and weathered granite ; in the latter two cases a cement concrete block 2 ft. thick is laid. When laid on rock, the surface was blasted, roughened and benched with reversed steppings. Foundations were of open type with boulder coffer dams—Depth ranged from 2'-8" to 30 ft. below bed.
6 Centering.	6 steel trusses weighing each 2.5 tons, supported by wooden stanchions on sand-filled steel cylinders which rest on cutstone bases, 9 inches thick on masonry extensions of piers and abutments. The centerings were erected and placed in position by a jib crane of 3½ tons capacity. With a total load after erection of 335·0 tons over the arch, pressure on each cutstone base is 33·5 tons.
7. Archs.	(a) *Springing.* 2 ft below maximum flood level. (b) *Rise.* 12 42 ft ; segmental, with a radius of curvature of intrados of 42·12 ft. Intrados subtends an angle of 90° at centre. (c) *Arch thickness.* 3'-3" at haunches and 2'-9" thick between ; face voussoirs all 3'-3" ; granite cutstone in surki mortar 1 : 1 : ½ (lime, sand and surki), with a murram filling of 1½ ft. at crown. (d) *Designed load.* 150 lbs. per sq. ft. of live-load. (e) *Drainage* provided by 4" diameter reinforced concrete pipes—4 numbers at the haunches and 2 at the crown (f) Iron rings were inserted in the arch for wooden platform for watering during construction, and for subsequent repair work.
8. Roadway.	20 ft. clear between curbs, which are 6" thick ; Parapets of cutstone 1'-6" by 3'-6" high including cutstone coping—width outside to

	outside of parapets 24 ft, wearing coat of cement concrete 4½ inches thick, over murram filling — Proportion of cement concrete was 1 . 1 75 : 4 22 (cement, sand and aggregate) designed on a rational basis.
9. Dewatering.	Heavy springs were met with 12 centrifugal pumps of 12 B H P. to 14 B H P and a total capacity of 5850 gals per minute, were used.
10. Time for completion	About 3 years with 682 working days Time taken for erecting the centering of one span was 12 days and for laying of the arch 10 days.
11. Total length of bridge from end to end of returns.	2198'-6".
12 Total cost of bridge.	Rs. 11,38,715 (British currency)
13. Cost per R. ft.	Rs 451 5.
14. Average Height of elevation from bottom of foundations to road level.	66 38.
15. Cost per sq ft. of elevation.	Rs. 6 9/-.

APPENDIX 2.

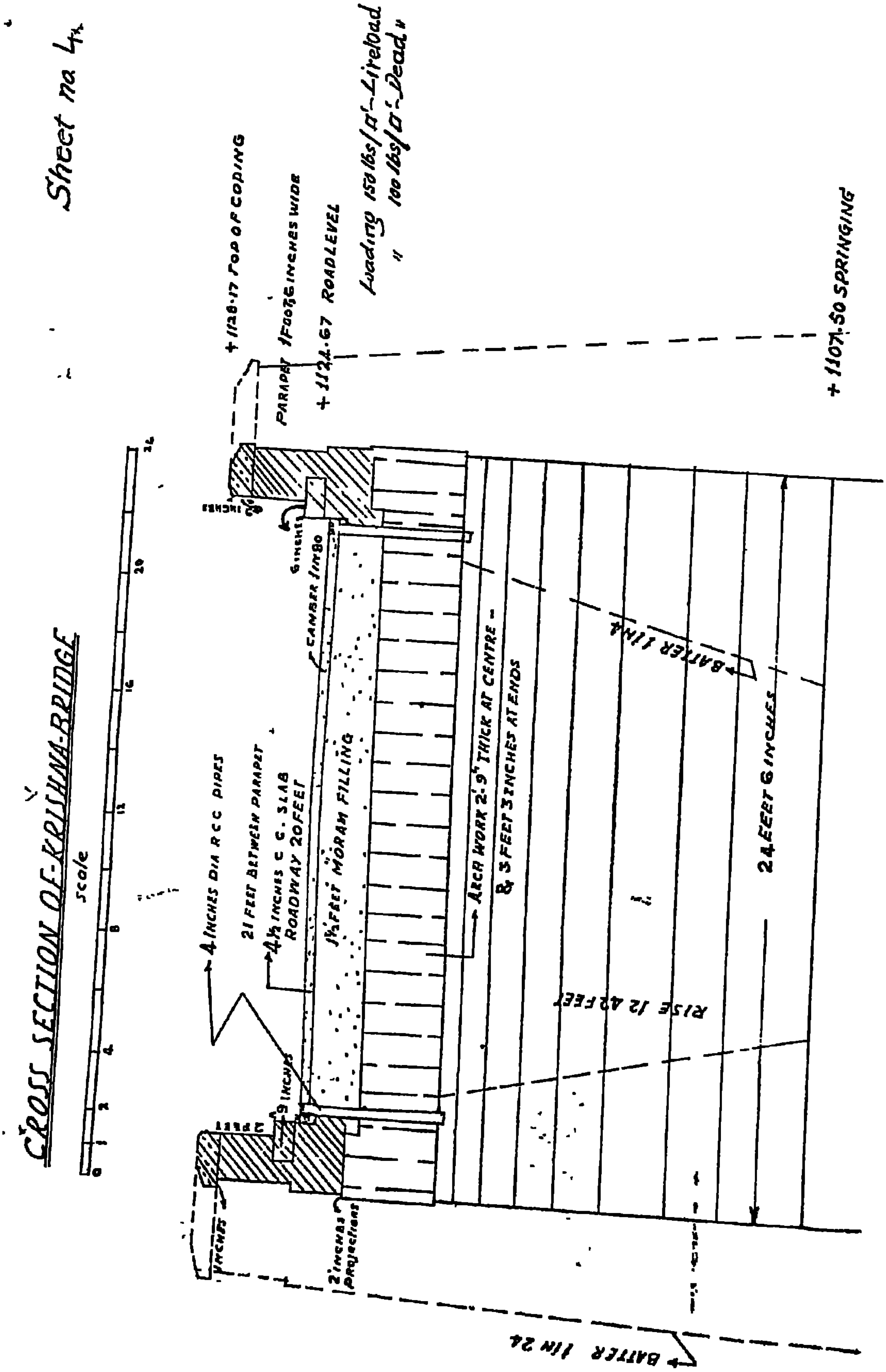
GENERAL ABSTRACT OF KRISHNA BRIDGE SHOWING THE QUANTITIES, AMOUNT, &c

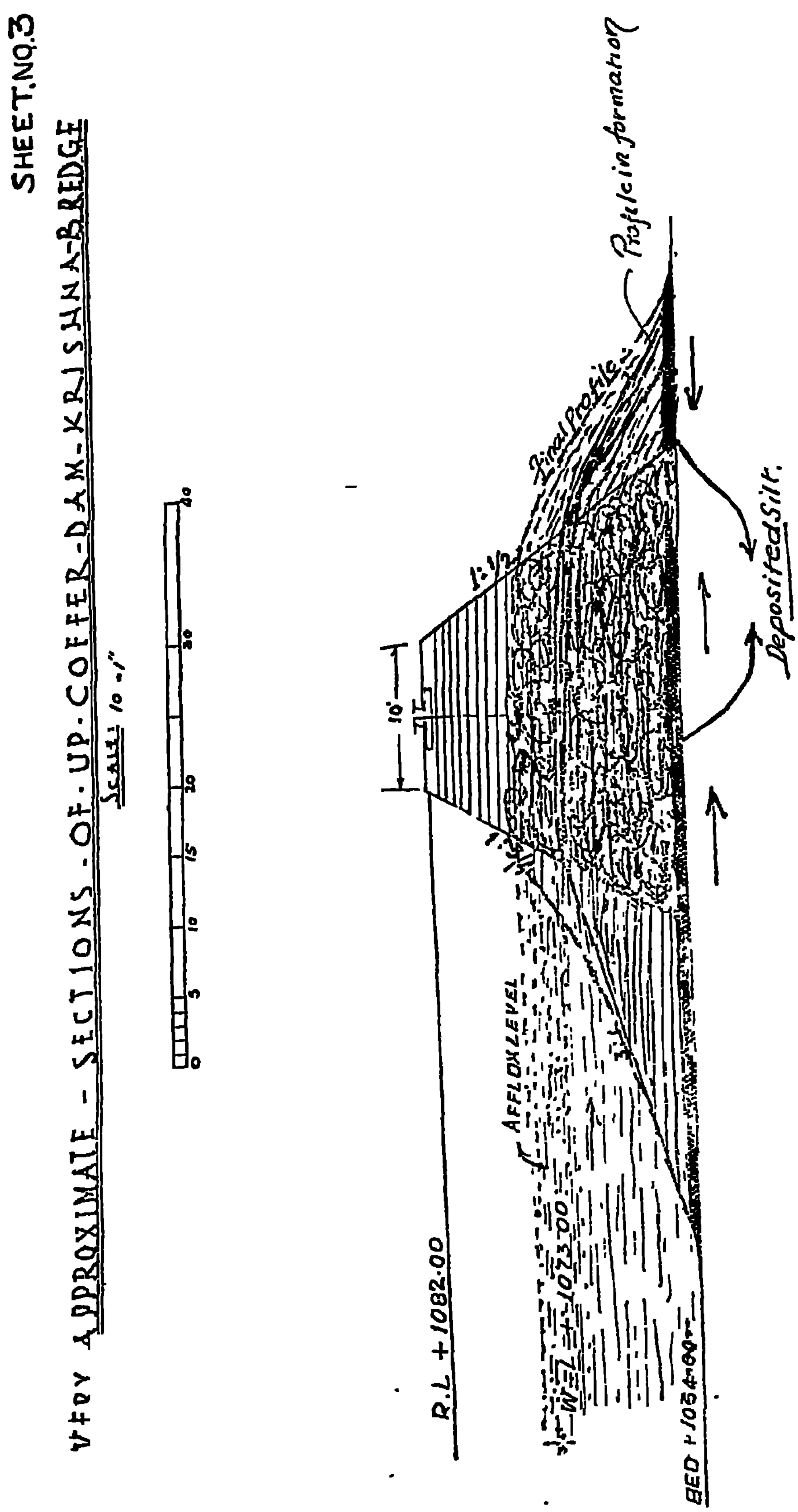
S.No.	Particulars.	Quantities.	Amount in Rs. (o s.)
1.	Excavating founds. ..	750.00 Uts:	47,815
2	Filling foundations. (i) cement concrete.	472.05 ,,	84,024
	(ii) with coursed rubble stone in surki mortar. ..	1762.87 ,,	
3	Superstructure including extra lift—coursed rubble stone in surki mortar. ..	7072.76 ,,	2,51,113
4.	Archwork including extra lift. ..	1948.21 ,,	2,78,575
5.	Centerings including cost, transportation charges, cost of new loggings, rectification and masonry for stanchion supports and depreciation etc.	7 sets of centrings	1,14,664
6.	Fine dressed coping stones ..	7012.56 Cft.	21,038
7.	Filling haunches. ..	568.82 Uts.	11,524
8.	Wheel guards. ..	5108 00 Rft.	7,509
9.	Muram filling over haunches. ..	240.89 Uts	4,818
10.	Dewatering founds. ..		78,437
11.	Temporary quarters. ..		13,500
12.	Tools and Plants. ..		60,913
13.	Cofferdams. ..	19.33 chains	89,172
14.	Miscellaneous items. ..		10,937
15.	Cost of approaches ..	Miles. 3 - Fur. 3	1,10,000
16.	L.S. under Chief Engineer's control. ..		14,838
17.	Supervision charges ..		83,390
18.	Contingencies. ..		46,233
	TOTAL COST (O.S.) Rs.		13,28,500

Extra cost for cement concrete wearing coat 4½″ thick over the bridge with 1 : 1.75 : 4.22 proportion on rational basis. . O S. Rs	27,000
Total o.s. Rs.	13,55,500

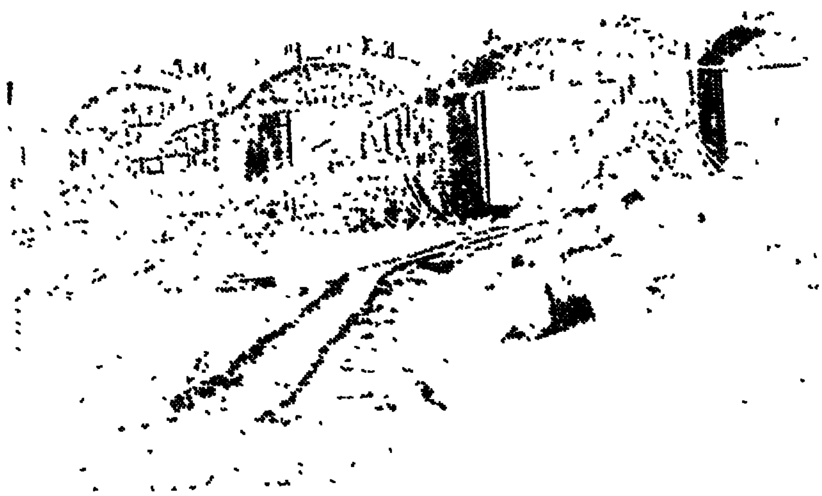
N.B—The cost of the bridge worked out in B.G. currency is Rs. 11,38,715.

Rate of exchange : O S. Rs. 116-10-8 = B.G. Rs 100-0-0


CROSS SECTION OF KRISHNA BRIDGE
Scale
Sheet no 4
+1128·17 TOP OF COPING
PARAPET 1 FOOT 6 INCHES WIDE
+1124·67 ROADLEVEL
Loading 150 lbs/□'-Liveload.
" 100 lbs/□'-Dead "
+1107·50 SPRINGING
4 INCHES DIA R C C PIPES
21 FEET BETWEEN PARAPET
4½ INCHES C. C. SLAB
ROADWAY 20 FEET
1½ FEET MORAM FILLING
CAMBER 1 IN 80
ARCH WORK 2'-9" THICK AT CENTRE -
& 3 FEET 3 INCHES AT ENDS
BATTER LINE
24 FEET 6 INCHES
RISE 12·42 FEET
BATTER 1 IN 24
2 INCHES PROJECTION


SHEET.NO.3
VERY APPROXIMATE - SECTIONS - OF - UP - COFFER - DAM - KRISHNA - BRIDGE
SCALE: 10 = 1"
0
5
10
15
20
30
40
R.L + 1082.00
W.L + 1073.00
BED + 1054.00
AFFLUX LEVEL
10'
1:1½
Final Profile
Profile in formation
Deposited Silt.

1. The pier No (4) showing the nature of the sides of foundation.



3. Bridge in Progress.

4. Bridge after completion.

Thursday, October 7th, 1943.

Mr. Ali Ahmed (Chairman) called upon Mr. Farhatulla to introduce his paper "Masonry Arch Bridge of 35 spans of 60 feet each across the Krishna at Devosugur."

The above paper was taken as read.

DISCUSSION.

Mr. Farhatulla (Author).—In introducing the paper, referred to certain mistakes in print. These are detailed below

Page	Para	Line	For	Read
299	1	12	Devosagar.	Devosugur.
,,	2	5	9.45 million cusecs.	9,45,000 cusecs.
,,	2	6	Chief Engineer of the State.	Consulting Engineer to H.E.H. the Nizam's Government.
,,	2	6	Mr.	To be omitted.
300	3	3	Cement mortar.	Surkhi mortar.
,,	4(iv)	..	During a period of acute famine.	Which is subjected to the constant visitation of famines and the local labour is consequently very poor in these parts
,,	5	1	High pilasters.	High pedestals.
,,	5	2	Arch all of cut-stone.	The arch is block-in-course with the front and the bottom of voussoirs having been finely dressed.
301	App 1 (4)		Whole paragraph.	Cut waters are purely triangular subtending an angle of 90° at the apex with their sides making angles of 45° with the faces of piers.
	App. 1 (6)	2	Supported by wooden stanchions on sand-filled steel cylinders.	Supported by steel stanchions placed over wooden blocks supported on boxed-sand in steel cylinders.
	App 1 (7)	(d)	Designed load 150 lbs. per sq. ft. of live-load.	150 lbs per sq. ft. of live-load + weight of filling at 100 lbs. per sq. ft. for 1 ft. depth or the weight of masonry at 150 lbs. per sq ft. for 1 ft. depth.
	App. 1(10)	1	About three years with 682 working days.	Total working period 682 days for sub-structure and 393 days for super-structure. In all 1075 working days.

Mr. K. S. Raghavachary (Simla)—

Mr Farhatulla has a legitimate grouse against me for having abridged his paper considerably As already noted in the footnote, this paper was received very late Having been included in the provisional programme, we were obliged to rush through this paper within a week I may perhaps mention in this connection that when I was at Hyderabad in June last, I had occasion to see the bridge which had then been recently completed and as this is a major masonry arch bridge of 60 ft span constructed with indigenous local materials such as stone, surkhi, lime, etc, without any cement, I requested Mr. Ahmed Mirza to have a paper written on this bridge for the advantage of the Indian Roads Congress He readily agreed and this paper is the result

It would greatly enhance the value of the paper, if the following points had also been dealt with

1. Detailed calculations for the design of the arch, the details of design adopted whether it is by elastic theory, or Fullers method, or whether Emperical formulae had been used

2. Usually arch is designed assuming the horizontal thrust at the crown to act at the extreme middle third points. But in this case it has been assumed that the thrust acts at the centre Also when the live-load is only on one-half of the arch the direction of this thrust will not be horizontal

3 Was any impact factor allowed in the design ? My own impression is that no impact allowance is necessary as the weight of the arch is considerable compared to the live load Also Ketchum recommends that no impact factor is necessary in the case of masonry arches with a crown filling of not less than 1 ft. 6 in

Mr. Farhatulla (Author) —It is very exhilarating after the turmoil of service for so many years to be drawn back to the good old college days when we were turning pages of our books, drawing stress diagrams and determining maximum and minimum stresses, coming into play because of the eccentric loading, and I am grateful to my friend Mr. Raghavachary who has so kindly offered me an opportunity to revive these sweet memories with the comments he has passed on my paper

I wish I had got these days back but alas they have gone away and never to return and the only consolation which they have left behind is their token which are our time old companions, the books.

Well, gentlemen, these companions which the Hyderabad P W D have provided me there and I assure you that their companionship has been fully availed of in the designing of the masonry arch for the Krishna Bridge. If you also wish to enjoy their companionship very early, my request of you is that you please purchase them

APPENDIX I.

LIST OF PAPERS IN ANNUAL PROCEEDINGS.

S. No	Subject of Paper	No. of Paper.	Name of Author.
	VOLUME I—1934.		
1	Objects and organisation of a permanent Indian Roads Congress.	1.	K.G. Mitchell, C.I E
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4.	Earth Road Construction and Maintenance by Machinery.	3.	G.W.D. Breadon.
5.	Earth Road Development and Stabilisation with Gravel.	4.	Lieutenant-Col. A.V.T. Wakely, D. S.O., M.C.
6.	Progress made in the use of Tar and Bitumen in the Punjab since the last International Roads Congress in Washington in October 1930.	5. (a)	S.G. Stubbs, O.B.E
7.	Notes on the Uses of Tar, Bitumens and Emulsions in the Punjab.	5. (b)	R. Trevor-Jones, M.C.
8.	Asphalt Roads.	6.	G.G.C. Adami.
9.	The Use of Cement Concrete for the Construction of Roads in the Bombay Presidency	7.	L.E. Greening.
10	Cement Concrete Roads.	8.	W.J Turnbull
11.	Concrete Roads in Hyderabad (Deccan).	9.	M.A Zeman.
12.	Corrugation for water-bound macadam road surfaces in the Bombay Presidency and a cure.	10.	Henry J.M. Cousens.
13	Notes on the Plant Used for Quarrying and Granulating and Operating Costs of the Gauhati-Shillong Road. Khasi and Jaintia Hills Division, Assam.	11.	B.F. Taylor, V.D.
14.	Some Physical Aspects of Roads and Tyres.	12.	G.E.W. Moss.
15.	Test Tracks - A suggestion.	13.	C.D.N. Meares.

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16	An Analysis of Delhi Road Traffic Census	14	R L Sondhi.
17	A study of the Relationship between Vehicular Traffic and Road Surfaces as affecting the Selection of an Economic Road Surface.	15	H.P. Sinha and A M. Abbasi
18	Traffic Census and Road Diagram	16	Lieutenant-Colonel W. deH Haig, D.S.O.
19	Economics of Road Maintenance.	17.	S Bashiram.
20	Necessity for Surface Treatment of important Tourist Lines and some aspects of Economical work in that direction.	18.	V.S. Srinivasaraghava Achariar.
21.	Treatment with Molasses of the Bangalore-Mysore Road	19	Diwan Bahadur N.N Ayyangar.
22	The Road Problem in India with some Suggestions	20	Colonel G.E. Sopwith.
23	General Review of the Results of Recent Road Experiments in India as revealed by Modern Practice.	21	K.G. Mitchell, C I.E., I S E
24.	Road Research and Results	22	C D.N Meares.
25	Road in Rural Areas (Village Roads).	23 (a)	Rao Bahadur Ch Lal Chand, O B E.
26	Gravel Roads	23. (b)	Diwan Bahadur N.N Ayyangar.
27.	Vitrified Bricks for Surfacing Roads in Deltaic Districts.	23 (c)	G. Gopala Acharya.
28.	Oil as a Binder for Earth and Gravel Roads	24.	T G F Hemsworth,
29.	Cement-bound Roads.	25.	W J. Turnbull.

S. No.	Subject of Paper	No. of Paper	Name of Author.
30.	The Necessity for a Reasonably Uniform Standard Loading for Design of Concrete Bridges and a Suitable Loading for Such aud Other Types of Bridges on Highways in India.	26.	M.G. Banerji.
31	Design of highway bridges The necessity for an All-India Specification.	27	W.A. Radice and P.F.C. Warren.
32.	Permissible Stresses in Concrete Bridge Design	28.	W.J. Turnbull.
33.	Regulation and Control of Motor Transport in Mysore.	29.	H. Rangachar.
34.	The Construction of the Shillong-Jaintiapur Road in the Khasi Hills, Assam.	30.	F.E Cormack.
35.	A Method of Rapid Road Reconnaissance.	31.	Captain W.G. Lang-Anderson.

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36.	Some Notes on the layout of Rural and Suburban Roads in the Punjab.	32.	R. Trevor-Jones, M.C.
37.	Roads and Public Health in India with special reference to Malaria, borrow pits and road dust.	33.	Raja Ram.
38.	Further Notes on treatments of Roads with Bitumen and Tar in Delhi Province.	34.	A W.H. Dean, M.C.,
39.	Economy and Developments of Bonded Brick Concrete Roads, Plain and Reinforced	35.	A.K. Datta.
40.	Ways and Means of Improving the Bullock-Cart.	36.	G.L W. Moss.
41.	Indian "Road-Aggregates", Their uses and Testing.	37.	R.L. Sondhi.
42.	Submersible Bridge across Parbati River at Mile 231, Agra-Bombay Road.	38.	Rai Bahadur S. N. Bhaduri.
43.	Optimum Weight of Vehicles on extra-municipal Road.	39.	K.G. Mitchell, C.I.E.

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44.	A method of calculating the Stability of Braced Pile Piers.	A (I)	Guthlac Wilson.
45.	The Dhakuria Lake Bridge	A (II)	-do-
46.	Franki Pile Foundations for Road Bridges.	B.	W A Radice.
47.	Reinforced Cement Concrete Bridges of 24 feet span constructed in Gwalior State.	C.	Rai Bahadur S N. Bhaduri.
48.	Reinforced Concrete Bridge across the Godavari River at Shahgadh in Hyderabad State.	D.	Dilar Hussain.
49.	Safe Wheel Loads for Indian Roads.	E.	K.G. Mitchell.
50.	Roads under Local Bodies and how to maintain them.	F.	Rai Saheb Fateh Chand.
51.	Corrugations on Road Surfaces.	G.	G B.E. Truscott.
52.	An Aspect of Traffic Statistics.	H.	Ian A.T. Shannon.
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53	Some Notes on Submersible Bridges.	I.	D. Nilson.
54.	Design of Reinforced Concrete Bridges of short Spans for Indian Roads.	J.	Brij Mohan Lal.
55.	Collection of Material for and Consolidation of Waterbound Macadam.	K (1)	R. Trevor-Jones, M.C.
56.	Layout of Roads	K (2)	-do-
57.	Some Aspects of Bituminous Road Construction in India.	L.	Colonel G.E. Sopwith.
58.	Ribbon Development.	M.	A.S Trollip
59	Soils in relation to Roads, A Bibliological Study.	N.	G.W. D. Breadon.
60.	The use of Soil Stabilisation in Unmetalled and Metalled Roads in India	O.	Sita Ram Mehra.
61.	Revitalization of Tarred or Bitumened Surfaces by Mix-in place Methods using Cut-Back Asphalt.	P.	Captain R.C. Graham.

S. No.	Subject of Paper.	No. of Paper.	Name of Author
62.	Surface Treatment of Concrete Roads when Outworn.	Q.	W.A. Radice.
63.	A Serious Failure in the Painting of a Steel Highway Bridge.	R.	W.L. Murrell.
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64.	Evolution of the Thin Concrete Road in the United Provinces.	A-39	W.F. Walker.
65.	Repair and Maintenance of Cement Concrete Roads.	B-39	Rai Bahadur A.C Mukerjee.
66.	Development and Application of Village Cement and High Silica Portland Cement for the Construction of Concrete Roads.	C-39	A.K. Datta.
67.	The Sai Bridge.	D-39	M.A. Komi.
68.	Present Day Methods of Bituminous Road surfacing work in Chota Nagpur, Bihar.	E-39	S.A. Amir.
69.	Stabilisation of the Unmetalled Berms of Metalled Roads.	F-39	S.R. Mehra.
70.	Light Bituminous Surfacings.	G-39	Ian A. T. Shannon
71.	An Economical Substitute for Waterbound Macadam.	H-39	A. Laksminarayan Rao.
72.	Slip and Subsidence in a Hill Road.	I-39	D.C. Datta.
73.	Roads in India and Australia-Our difficulties and some Suggestions.	J-39	W.L. Murrell.
74.	Standardization.	K-39	D. Nilson.
75.	Impact of Reinforced Concrete Road Bridges as compared to Steel Bridges.	L-39	E.P. Nicolaides.
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76.	Intermediate Screw Piles for the Foundation of Bridges in Soft Soils.	A-40	M.S. Doraswamy Ayyangar.
77.	The Failure of a Multi-Arched Masonry Bridge.	B-40	S.K. Ghose.
78.	Transition Curves for Roads	C-40	W.R. Fleury.
79.	Trackways for Rural Road Development.	D-40	Sir K.G. Mitchell.

APPENDIX II

SUBJECT INDEX

Classification.

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2	Safe wheel loads for Indian Roads.	K. G. Mitchell & Jagdish Prasad.	IV.	E.	1 (e) to 32 (e).	49
3	Corrugations on road surfaces.	C. B E. Trustcott.	IV.	G.	1 (g) to 24 (g)	51
4	Ribbon Development.	A. S. Trollip.	V.	M.	1 (m) to 30 (m).	58
5	Slip and subsidence in a hill road.	A. C. Datta.	VI.	I-39.	1 (i) to 17 (i).	72
6	The Broad classification of Traffic and contributory causes of wear and tear of roads.	Sir Kenneth Mitchell.	VIII.	A-41.	1 to 4 (b)	85

II. Road surveys, Design, Layout and Construction.

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1	Construction of Shillong Jaintipur Road, Khasi Hills, Assam.	F. E. Cormack	II.	30	390-397	34
2	A method of rapid road reconnaissance.	Captn W.G Lang Anderson.	II	31	398-416	35
3	Some notes on the layout of rural and suburban roads in the Punjab.	R. Trever Jones.	III.	32	10-26	36
4	Optimum weight of vehicles on extra-municipal roads.	K G. Mitchell.	III	39	92-105	43
5	Layout of Roads	R Trever Jones.	V.	k (ii)	4 (k) to 17 (k) 18 (k) to 43 (k2)	56
6	Transition curves for roads	W. R Fleury	VII	C 40.	15 to 47	78

III. Soil and Earthworks, soil Science as adapted to Road foundation, Banks, and Earth surfaces, Soil stabilization, etc.

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1	Earth road construction and maintenance by machinery.	G.W.D. Breadon.	I.	3	90-105	4
2	Earth Road Development and stabilization with gravel.	Lt. Col A.V.T. Wakley.	I.	4	68-89	5
3	Roads in Rural areas (village roads)	Rao Bahadur Chowdhary Lal Chand.	II.	23 (a).	191-194 227-233	25
4	Oil as binder for earth and gravel roads.	T. G. F. K Hemsworth.	II.	24	205-233	28
5	Soils in relation to Roads—A bibliological study.	G. W. D. Breadon.	V	N.	1 (n) to 12 (n).	59
6	The use of soil stabilization in unmetalled and metalled roads in India	S. R Mehra.	V.	O.	1 (o), to 21 (o).	60
7	Stabilization of unmetalled berms of metalled roads.	S R. Mehra.	VI.	F-39.	1 (f) to 25 (f).	69
8	The use of soil stabilization in unmetalled and metalled roads in India.	S. R. Mehra.	VII.	H-40.	135-156 (g).	83
9	Some experiments to stabilise moorum roads in Chota Nagpur.	K Gupta.	VIII.	D-41.	57 to 74(b)	88

Serial No.	Name of paper.	Name of author.	Reference to Proceedings. Volume No.	No. of paper in volume.	Pages.	Serial No. of paper in general index.
10	Fundamentals of soil mechanics.	F. D. L. Woolterton	VIII.	L-43.	211 to 298 (b)	96

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1	Corrugation of waterbound macadam road surface in the Bombay Presidency and a Cure.	Henry J. M. Cousens.	I.	10	184-189	12
2	Some physical aspects of roads and tyres.	C. L. W. Moss.	I.	12	190-198	12
3	Treatment with molasses of Bangalore-Mysore Rd.	N. N. Ayyangar.	II.	19	105-109 125-130	21
4	Gravel Roads.	N. N. Ayyangar.	II.	23 (b).	199-203 227-233	26
5	Vetrified bricks for surfacing roads in deltaic districts.	Gopalacharya.	II.	23 (c).	111-116 125-130	27
6	Roads under local Bodies and how to maintain them.	R. S. Fateh Chand.	IV.	F.	1 (f)-20 (f).	50
7	Collection of material for and consolidation of water-bound macadam.	R Trevor Jones.	V.	K (1).	1 (k)-5 (k) 6 (k1)-40 (k1).	55
8	Some notes on the maintenance of water-bound macadam.	R.B. A L. Rao.	VIII.	G-43	151-155H	91

V. Tar and Bitumen Surfacing : Carpets, etc.

1	Recent methods used for the treatment of roads with bitumen and tar in Delhi Province.	A. W. H. Dean	I.	I. (*a*)	21 to 50 56 to 67	2
2	Progress made in the use of tar and bitumen in the Punjab since the last International Road Congress in Washington in October 1930.	S. G. Stubbs..	I.	5 (*a*)	121-134 168-182	6
3	Notes on the use of tar, bitumen and emulsions in the Punjab.	R. Trevor Jones.	I.	5 (*b*)	135-145 168-182	7
4	Asphalt Roads ..	G. G. C. Adami.	I.	6	146-182	8
5	Necessity for surface treatment of important tourist lines and some aspect of economical works in that direction.	V. S. S. Acharya.	II	18	74-83 93-104	20

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7	Further notes in the treatment of Roads in Delhi Province, with bitumen and tar.	A W H. Dean	III	34	27- 63	38
8	Some aspects of bituminous road construction in India.	Col. C E Sopwith and W A Griffith.	V	L	1 (l) to 24 (l).	57
9	Revitalisation of tarred or bitumened surfaces by mix-in-place methods using cut-back asphalt	Capt R. C. Grahan	V	P.	1 (p) to 12 (p).	61
10	Surface treatment of concrete roads when outworn.	W A Radice.	V.	Q	1 (q) to 18 (q).	62
11	Present day methods of bituminous road surfacing work in Chota Nagpur, Bihar	S A. Amir	VI.	E-39	1 (e) to 15 (e).	68
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15	Notes on drag spreading and drag-brooming.	W. L Murrell	VII.	I-40	157 to 190 (o)	84
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2	Cement concrete roads	W J Turnbull	I.	8	217-230 136-258.	10
3	Concrete roads in Hyderabad (Deccan)	M A. Zaman	I	9	231-252	11
4	Cement bound roads	W J Turnbull.	II	25	117-130.	29
5	Economy and development of bonded brick concrete roads, plain and reinforced	A.K Datta	III	35	106-136	39
6	Evolution of the thin concrete road in the United Provinces.	W F Walker.	VI	A-39	1 (a) to 31 (a).	64
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9	Cement concreting the Bombay-Poona Road.	W.H E Garrod.	VIII.	K-43	203 to 216 (h).	95

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2	Submersible bridge across Parbati at mile 231, Agra-Bombay Road.	R.B S N. Bhaduri.	III.	38	176-234.	42
3	A method of calculating the stability of braced pile piers.	Gathlac Wilson.	IV.	A (i)	1(a)-1(a) & 23 (a).	44
4	The Dhakuria lake bridge.	"	IV.	A (ii) (a).	17(a)-23	45
5	Franki Pile foundations for bridges	W. A. Radice	IV.	B.	1 (b)-29 (b).	46
6	Reinforced cement concrete bridges of 24 ft. span constructed in Gwalior State.	R. B S. N. Bhaduri.	IV.	C.	1 (c)-20 (c)	47
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12	Intermediate screw piles for the foundation of bridges in soft soils.	M. S. Doraiswamy Iyengar.	VII.	A-40	1 and 2.	76
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17	Masonry Arch Bridge across the Krishna at Devosugur Hyderabad (Deccan)	Md Farhatullah.	VIII	M-43	299-303	97

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3	Study of relationship between vehicular traffic and road surface as affecting the selection of economic road surface	H P Sinha and A M. Abbasi.	II	15	29- 39 46- 62	17
4	Traffic census and road diagrams	Lt -Col. W De H Haig	II	16	40- 45 46- 62	18
5	Economics of road maintenance.	S Bashiram	II	17	63- 72 93-104	19
6	Regulation and control of motor transport in Mysore	H Rangachari	II.	29	234-255	33
7	An aspect of traffic statistics	Ian A. T. Shannon.	IV.	H	1 (h)-6 (h)	52
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2	Steel tyre problem unfolds.	W L Murrell	VII	E-40	67-77 (k).	80
3	Raising the Road-Rupee Ratio with a special reference to the steel tyre	W. L. Murrell	VIII.	C-41	43 to 56 (g)	87
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APPENDIX III.

LIST OF MEMBERS.

(Corrected upto 1/4/44)

ORDINARY MEMBERS.

Government of India

1. Mckelvie, G. M., Esq., Consulting Engineer to the Govt. of India (Roads), Simla.
2. Mitchell, Sir Kenneth, Controller of Road Transport, War Transport Department, New Delhi.
3. Raghavachary, K. S., Esq., Assistant to the Consulting Engineer, Govt. of India (Roads), Simla.
4. Vesugar, J., Esq., Development Officer, Post War Industrial Departt., Industries & Civil Supplies Departt., New Delhi.

C P.W.D.

5. Annaswami, V. S., Esq., Executive Engineer, C.P.W.D., Pandaveshwar, Burdwan.
6. Bazaz, Sham Lal, Esq., Quantity Surveyor, C P.W.D., New Delhi.
7. Browne, C. A., Esq., Supdg. Engineer, C.P.W.D., 15/1, Chowringhee Square, Calcutta.
8. Bhupendra Nath, Esq., Temporory Engineer, Plants Sub-Division, Bengal Aviation, Headquarters Division, 15/1, Chowringhee Square, Calcutta.
9. Chopra, A. N., Esq., Executive Engineer, C P.W.D., New Delhi.
10. Chowla, P. D., Esq., S.D.O., C.P.W.D., Construction Division, No. 1, New Delhi.
11. Dean, A.W.H., C.I.E., M C., Chief Engineer, C.P.W D., New Delhi.
12. Das, B. C., Esq., S. D. O., C. P. W. D., Chittagong.
13. Datta, A. K, Esq., S.D.O., C.P.W.D, P O. Ukhra Dist. Burdwan (Bengal).
14. Govel, K. C., Esq., Executive Engineer, Special Division No. 1, C.P.W.D., New Delhi.
15. Gupta, N. Das, Esq., S.D.O., C.P.W D, Salna, Kharagpur P.O.
16. Khattack, A. K, Esq., Executive Engineer, Special Division, Regal Buildings, New Delhi.
17. Khan, M. I., Esq, Executive Engineer, C P.W.D., Gaya (Bihar).
18. Manohar Nath, Esq., 55, Babar Road, New Delhi.
19. Mathur, M.S, Rai Bahadur, Superintending Engineer, Special Circle No. 1, C P W D., New Delhi.
20. Mehta, Javir Chand, Esq., S.D.O, C. P. W. D., Digri Camp, P. O. Sat Bankura (Midnapore).
21. Mehta, N. N., Esq, S.D O., 3rd Division, C.P.W D., Deoli (Rajputana)
22. Moghal Mohd, Yusaf, Esq., Asst. Executive Engineer, Construction Division, Dehra Dun.

23. Paterson, H J., Esq.,
Supdg. Engineer, Eastern Aviation Circle, 15/1, Chowringhee Square, Calcutta.

24. Puri, B. S., Esq.,
Executive Engineer, Central P.W.D., New Delhi

25. Ramasundaram, U. S., Esq.,
Superintending Engineer, C P.W.D., 15/1, Chowringhee Square, Calcutta.

26. Saha, S. L., Esq.,
S.D.O., C.P.W.D., Pandaveswar, Dist Burdwan.

27. Sinha, H. P., Esq.,
Executive Engineer, B, and U.P. Works, Central Division, C.P.W.D., Dehra Dun.

28. Saigal, Balbir Singh, Esq,
S D.O., C P. W. D., Prem Nagar Sub-Division,
Dehra Dun

29. Wadley, K. L. H, Esq,
Superintending Engineer, Eastern Aviation Circle, 15/1, Chowringhee Square,
Calcutta.

Other Members at Delhi.

30. Campbell Gray, T, Esq,
Block "M", Sorajnarain Building, Connaught Circus, New Delhi

31. Gharpura, A. V., Esq,
Superintending Engineer, The Indian Hume Pipe Co. Ltd., Delhi

32. Gupta, J N. Das, Esq.,
29, Nicolson Road, Delhi

33 Gupta, S L, Esq.,
Municipal Engineer, Delhi Municipality, Delhi

34. Hari Chand, Rai Sahib,
The Concrete Association of India, 70, Queensway, New Delhi.

35. Ishtiaq Ali, Esq,
Assistant Municipal Engineer,
Delhi.

36. Khanna, Inder Narain, Esq.,
Asphalt Road Engineer, Standard Vaccum Oil Co., 9, Babar Road, New Delhi.

37. Rowlands, W. H, Esq,
Technical Assistant, Burmah Shell Oil Co, New Delhi.

38. Rastogi, K. S., Esq.,
Consulting Engineer, 24, Fire Brigade Lane, New Delhi

39. Sopwith, C E., Col.,
C/o Maiden Hotel, Delhi.

40. Wazir Dayal,
4, Curzon Road, New Delhi.

Madras

41. Balakrishnayya, P., Esq.,
District Board Engineer, Waltair P. O.

42. Balasubrahmanyam, B., Esq.,
Assistant Engineer, P.W.D., Roads Sub-Divn.,
Trichinopoly.

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District Board Engineer, Chittoor (Madras)

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Municipal Engineer,
Trichinopoly.

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Municipal Engineer,
Coimbatore.

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District Board Engineer, Guntur (Madras Pres)

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Proddatur, Cuddapah Dist.

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District Board Engineer, Ellore P. O. (Madras Presidency).

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Assistant Engineer, P.W.D., Tirupati,

51. Krishnaswamy, P.A., Esq., Office of the Supdg. Engineer, Communications, Chepauk, Madras.

52. Krishnan, K. S., Esq., Assistant Engineer, P.W.D. No. 15, Sripuram Street, Rayapetta, Madras.

53. Kutty Krishnan, O.C., Esq., Roads Engineer, C/o The Standard Vacuum Oil Coy., P.B. No. 115, Madras.

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66 (a) Padhe, Harish Chandra, Esq., Assistant Engineer, Chicacole, Vizag. Dt.

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68. Ramamurti, K., Esq., Municipal Engineer, Masulipatam.

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District Board Engineer,
Nellore (Madras).

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District Board Engineer,
Ootacamund.

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Engineer, Corporation of
Madras, Madras.

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Asst. Engineer, P. W. D.,
P.O Villivakkaam, Ambattur, *Madras*

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Asst. Engineer, Belmont,
Fernhill, Nilgiris.

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Municipal Engineer,
Bezwada

85\. Subrahmanyam, K.S, Esq,
Office of the Superintending
Engineer, Communications,
Trichinopoly.

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District Board Engineer,
Tanjore (Madras).

87\. Sundaram Pillai, N.P., Esq.,
District Board Engineer,
C/o Supdg. Engineer,
Communications, Madras.

88\. Tirumalaiswami Ayyar, K.,
Rao Bahadur,
Supdg Engineer, Communications, Trichinopoly
(Madras).

89\. Venkatakrishna Iyer, L,
Rao Bahadur,
Chief Engineer (retired),
P.W D., 17, Cathedral Rd,
Cathedral P.O, Madras

90\. Venkataramanaraju, P., Esq.,
Supdg. Engineer, A. R. P.,
Chepauk, Madras.

91\. Venkatasubrahmanya Iyer,
C. S, Esq.,
'Khosalam', Abhirampuram,
2nd St., Bhumanipet, Mylapore, Madras

Bombay

92\. Adke, A. S, Esq.,
District Engineer, District
Local Board, Dharwar.

93\. Bannerjee, H. F., Esq.,
Chief Electrical and Mechanical Engineer, Dawn Hills,
Ferguson Road, Bombay, 13

94\. Bannerjee, Tulsidas,
Rao Sahib,
Chikalvadi Road, Kirkee.

95 Bathwala, H. S., Esq,
Dist. Engineer, Bombay
Dist., Concrete Association
of India, Bombay.

96 Bhate, K G., Esq.,
Asst Engineer, P. W. D,
Office, Kaira.

97\. Barucha, M D, Esq.,
C/o The All India Construction Co, Ltd., Wittet Rd.,
Ballard Estate, Bombay.

98\. Bhandarkar, G. P., Esq.,
Retd Chief Engineer, Holkar
State, Plot No. 56, Sion
Road, Bombay 22.

99\. Burn-Lawson, A, Esq.,
C/o The Hindustan Construction Co., Ltd, Ballard
Estate, Bombay.

100 Chinchankar, K. B, Esq,
Engineer and Contractor,
573/4, Shanti Niketan,
Jungli Maharaj Road,
Poona.

101\. Choksi, B K, Esq.,
C/o P. W. D., Bagalkot,
Dist. Bijapur.

102\. Clayton, R., Lt. Col.,
Comouflage School (India),
Kirkee.

103\. Daftary, G. D., Esq,
Chief Engineer and Secretary to Govt. of Bombay,
P.W.D., Bombay.

104\. Doshi, M. M, Esq.,
C/o The Indian Hume Pipe
Co, Ltd., Murbid Road.
Kalyan.

105. Edwin, J. W., Esq., Executive Engineer, Bombay Aviation Division, Commerce House, Ballard Estate, Bombay.

106. Endlaw, D. N., Esq., Executive Engineer, Bombay Aviation Division, Commerce House, Ballard Estate, Bombay.

107. Garrod, W.H.E., Esq., Chief Engineer, P. W. D., Bombay.

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110. Golwala, P. E., Esq., Civil Engineer, C/o Chief Engineer, Bombay Port Trust, Fort, Bombay.

111. Gough, D. E., Esq., The Society of Motor Manufacturers Traders, Ltd., National Insurance Buldgs. 27, Bastion Road, Fort, Bombay.

112. Goghari, N W., Esq., S.D.O., P.W.D., Canal Sub-Divn., Ahmedabad.

113. Joshi, N. S., Rao Bahadur, Executive Engineer's Bungalow, Satara.

114. Joshi, Sitaram Balakrishna, Esq., Examiners' Press Building, Dalal Street, Fort, Bombay.

115. Joglekar, G.D., Esq., Executive Engineer, District Local Board, Thana, Bombay Presidency.

116. Kothari, H.J., Esq., Roads Engineer, Messrs. Burmah Shell Co. of India, Ltd., Ballard Estate, Bombay.

117. Kynnersley, T.R.S., Esq., Chief Engineer, Concrete Association of India, Hamam Road, Bombay.

118. Mabida, U.N., Esq., Poona Irrigation Research, Poona.

119. Manson, J.A.S., Esq., Executive Engineer, P.W.D., Nasik.

120. Maswani, V.M., Esq., Indian Hume Pipe Co., Ltd., Construction House, Ballard Estate, Bombay.

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125. Nicolaides, E.P., Esq., Chief Designer, Messrs. J.C. Gammon, Ltd., Hamilton House, Bombay.

126. Pancholy, H.M., Esq., Saraswati Society, Ellise Bridge, Ahmedabad.

127. Patil, B D., Esq., Municipal Engineer, Ahmedabad.

128. Parikh, H.B., Esq., 17, Sidhavina, Narsingh Lane, Malad.

129. Plunkett, P.A., Esq., No 6, Salisbury Park, P.O. Box No. 15, Poona.

130. Ratnagar, R.D., Esq., 'Monrepos' Land's End, Bandna, Bombay 20.

131. Rege, S.B., Esq., Executive Engineer, Nasik Division, Nasik.

132. Rege, D.Y., Esq.,
C/o Standard Vacuum Oil Co., Neville House, Ballard Estate, Bombay.

133. Sandhawalia, N S., Esq ,
C/o Shalimar Tar Products, Ltd., 16, Bank Street, Bombay.

134. Sanjana, N P., Esq.,
Engineering Assistant, Chief Engineer's Office, Bombay Port Trust, Ballard Estate, Bombay.

135 Shannon, Ian A T , Esq.,
C/o The Burmah-Shell Oil Company, Imperial Chemical House, P B No. 688, Ballard Estate, Bombay.

136. Smith, H C , Lt Col ,
C/o I.R.T D A. Ltd , 41, Nicol Road, Ballard Estate, Bombay.

137. Sowani, D G., Esq ,
Estate and City Improvement Officer, Ahmedabad *Municipality*, *Ahmedabad*.

138. Sukhatankar, V.M , Esq.,
District Engineer, District Local Board, Belgaum

139. Trollip, A S , Esq.,
Hony. General Secretary, The Safety First Association of India, Electric Lane, Fort, Bombay.

140. Tyabji, S.B , Esq ,
Somerset Lodge, Worden Road, Cumballa Hill, Bombay

141. Turnbull, W.J , Esq.,
C/o Shalimar Tar Products, 16, Bank Street, Bombay.

142. Vagh, B V., Esq.,
Road Engineer, Burmah Shell Oil Distg Co. of India, Ltd , Bombay.

143. Vartak, G R., Esq ,
District Local Board Engineer, Satara City.

144. Vaze, D L., Esq.,
C/o Messrs. Vaze Balangi, Examiner's Press Bldgs., Meadows Street, Fort, Bombay.

145 Wale, N D. Esq ,
Special Engineer, Municipal Borough, Hubli, District Dharwar.

Bengal

146. Bannerji, M. G., Esq.,
Controller of the Stores, Calcutta Corporation, 140, Lower Circular Road, Calcutta.

147. Bhattacharya, H , Esq.,
Executive Engineer, Department of Communications and Works, Comilla.

148. Bose, R K , Esq.,
Executive Engineer, Bakarganj Division, Barisal (Bengal).

149. Bose, K N., Esq.,
Executive Engineer, C. & W. D., Rajshahi (Bengal).

150. Chatterton, Kenneth, Esq.,
Manager, Structural and Bridge Building Department, Burn & Co., Ltd., Calcutta.

151 Chatterjee, S C , Esq.,
Supdg. Engineer, Dacca (Bengal)

152. Chambers, J., Lt. Col.,
Chief Engineer, Bengal P. W. D., Calcutta.

153. Chakravarti, S. N., Esq ,
Municipal Engineer, Dacca.

154. Chatterjee, G C., Esq.,
Mirzapur Street, Calcutta.

155 Chatterjee, R., Esq.,
Executive Engineer, Burdwan Division, Hoogly.

156. Chatterjee, Dina Bandhu, Esq.,
C/o R. S. A T. Chatterjee, Kankgially, P. O. Chinsura, District Hoogly.

157. Dutta, P. R., Esq.,
Executive Engineer,
C. & W. Department,
Suburban Division, Calcutta.

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Executive Engineer, Higli
Division, Calcutta.

159. De, S. N., Esq.,
Assistant Engineer, Kurseong
Sub-Division, Kurseong
(Darjeeling).

160. Dam, S.C., Esq.,
23, Southern Avenue,
Calcutta.

161. Desai, D.S., Esq.,
C/o Messrs. Braithwaite
and Company (India),
Ltd., Hide Road, Calcutta

162. Datta, A. K., Esq.,
Consulting Engineer and
Master Builder, 5, Hastings
Street, Calcutta.

163. Dunbar, H. M., Captain,
Chief Engineer, Factories,
34, Park Street, Calcutta.

164. Fielder, C. J., Esq.,
C/o Messrs. Turner
Morrison and Co., Ltd.,
Calcutta.

165. Gilmore, E. F. G., Esq.,
8, Royal Exchange Place,
Calcutta.

166. Guha, J. C., Esq.,
Office of the Chief Engineer,
C. & W. Department,
Writers' Buildings, Calcutta.

167. Gue, K. C., Rao Bahadur,
District Engineer, Jalpaiguri.

168. Gupta, Indu Bhushan Das, Esq.,
Executive Engineer, C.&W.
Department, Darjeeling.

169. Gupta, N. C. Das, Esq.,
Assistant Engineer,
Communications and
Works Department,
Calcutta.

170. Ham, H. W. T., Esq.,
Managing Director,
Braithwaite and Company,
Hide Road, Kidderpore,
Calcutta.

171. Hoghshaw, F. H., Esq.,
Special Officer, Roads Fund
Works, C/o Chief Engineer,
C. & W. Dept., Writers'
Buildings, Calcutta.

172. Jardine, Alexander, Esq.,
Director, Jessop & Co. Ltd.,
93, Clive Street, Calcutta.

173. Keatinge, H. A., Esq.,
Executive Engineer, P.W.D.,
Darjeeling.

174. Kerr, J. Oldfield, Esq.,
C/o Burmah Shell Oil Co.,
Ltd., Post Box No. 360,
Calcutta.

175. Kirk, E. S., Esq.,
C/o Braithwaite Burn &
Jessop Construction Co.
Ltd., Mercantile Buildings,
Lal Bazar, Calcutta.

176. Korni, M. A., Dr.,
2, Bishop Lefroy Road,
Calcutta.

177. Lloyds, M. E., Esq.,
C/o The Standard Vacuum
Oil Co., Calcutta.

178. Malik, D. N., Esq.,
Executive Engineer,
Jalpaiguri.

179. Marik, Tarapada, Esq.,
Executive Engineer, Higli
Division, C. & W.
Department, 8, Lyons
Range, Calcutta.

180. Mitra, T., Esq.,
Supdg. Engineer, Darjeeling.

181. Morgan, I., Esq.,
103, Clive Street, Calcutta.

182. Mookerjee, B. N., Esq.,
C/o Messrs. Martin & Co.,
12, Mission Row, Calcutta.

183. Mukerjee, R. N., Esq.,
41/1, Elgin Road, Calcutta.

184. Mukherjee, S. N., Esq.,
Consulting Engineer and
Architect, Raghunath Ganj,
Dist. Murshidabad.

185. Maujumdar, Santosh Kumar, Esq., Bhowanipore T M.C A, 73, Puddapukar Road, P.O Elgin Road, Calcutta.

186. Mukherji, P K, Esq., 28, Ahiris Oikes Street, Calcutta.

187. Naugerede, C E de la, Esq., Garrison Engineer, Dacca.

188. Naziruddin, K, Esq, 12, Circus Avenue, Calcutta.

189. Nunn, Alfred Henry, Esq., Executive Engineer, Chittagong (Bengal).

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191 Roy, T. K, Esq, District Engineer, Dacca, Bengal.

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193. Sen, G, Esq, District Engineer, Midnapore (Bengal).

194. Stein, J. A., Esq, C/o Llyods Bank, 6, Palmal, S. W. I, London

195. Sarker, B N., Esq., Executive Engineer, Rajshahi (Bengal).

196. Sujan, S. B, Esq., District Engineer, Concrete Association of India, Victoria House, Calcutta.

197. Tandy Green, C. W., Esq, Superintending Engineer, Presidency Circle, Imperial Secretariat Buildings, No. 3, Govt. Place West, Calcutta

198. Tweed, J C Rathlin, Esq, Works Manager, Braithwaite & Co, Ltd, Hide Road, Kidderpore, Calcutta.

199. Warren, P F S, Esq., Director, Jessop & Co., Ltd, 93, Clive Street, Calcutta.

United Provinces

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The Punjab.

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246\. Eccleston, W. D., Esq.,
Executive Engineer,
124, Mayo Road, Lahore.

247 Freak, L A., Esq,
Chief Engineer, Punjab, P. W. D. Secrtt., B. & R. Branch, Lahore

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Asst. Engineer, P.W. Deptt., Amritsar.

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Supdg Engineer, Rawalpindi.

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Municipal Engineer (B. & R), Municipal Committee, Amritsar.

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Executive Engineer, P.W.D., B & R. Br., Gurgaon

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Executive Engineer; P.W.D., Multan Cantt.

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Municipal Engineer, Public Health, Amritsar.

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Executive Engineer, P.W.D, Aerodromes Divn., Chakwal, Dist. Jhelum

264\. Nayyar, Sohan Lal, Esq,
Municipal Engineer (B. & R.) Lahore Corporation, Lahore.

265\. Nagarkar, D.B, Esq.,
C/o The Concrete Association of India, Oriental Buildings, The Mall, Lahore

266\. Parang, Hari Ram, Esq.,
Retd. Executive Engineer, Lal Chowk, Quila Gujar Singh, Lahore

267 Puri, A. N., Dr,
Director, University Chemical Laboratory, Lahore

268\. Radha Krishna, Esq,
S. D O, P. W. Dept, Lyallpur

269\. Sharma, K. R., Esq,
Prof of Civil Engineering, McLagan Engineering College, Lahore

270\. Sharma, D C., Esq.,
Executive Engineer, Construction Divn., Gurdaspur.

271\. Sondhi, R. L, Esq,
Executive Engineer, 3, College Road, Lahore.

272\. Sri Ram, Esq.,
Chartered Engineer, 10, The Mall, Lahore.

273\. Trevor Jones, R., Esq,
Retd Chief Engineer, C/o Chief Engineer, P W D, B & R Branch, Lahore

274\. Varma, P L., M. B. E.,
Supdg Engineer, B & R. Br, Lahore

275. Waheed, M. A., Esq.,
Asst. Executive Engineer, P. W. D., Gurdaspur Construction Sub-division, Gurdaspur.

276. Whishaw, W.B., Col., O.B.E., M. C.,
Deputy Chief Engineer, Lahore Dist., Lahore Cantt.

C. P and Berar

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C/o The National Bank of India, Nairobi, Kenya.

270. Cochrane, G.A.D., Esq.,
Superintending Engineer, P.W.D., Raipur (C.P.).

279. Dave, D.P., Esq.,
District Engineer, Akola.

280. Devasthala, K.B., Esq.,
District Engineer, Distt. Council, Yeotmal (C.P.)

281. Ghanekar, Y.K., Esq.,
Assistant Engineer, Kaores Bungalow, Dharampeth (Nagpur)

182. Kane, V.S., Esq.,
C/o The Hindustan Construction Co., Ltd., Khamia Post, Jubbulpore.

283. Newton, B. St. J., Esq,
Chief Engineer, C.P. & Berar, P W D, Nagpur.

284. Roy, C.B., Esq.,
Supdg Engineer, Nagpur.

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Resident Engineer, R.S. Devji Dharsi and Sons, Military Works, Katni (C.P.)

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Executive Engineer, Bilaspore.

287. Tripathi, S.N., Esq.,
Assistant Engineer, No. 1, Aerodromes, Raipur (C.P).

Bihar

288. Aga, A.K., Esq.,
Deputy Chief Town Engineer, Tata Iron and Steel Co., Ltd., Jamshedpur.

289. Akhtar, S.E., Esq.,
Assistant Engineer, Post Office Bihta (Patna).

290. Amir, S.A., Esq.,
Superintending Engineer, Chhota Nagpur Circle, Ranchi.

291. Bahl, M.L., Rai Bahadur,
Superintending Engineer, P.W.D., Muzaffarpur (Bihar).

292. Bhattacharya, S.K., Esq.,
Peace Road, Lalpur, Ranchi.

293. Came, W.G., Esq..,
Chief Engineer, Bihar P.W.D., Patna.

294. Chadda, S.R., Esq.,
Resident Engineer, A.C.C., Ltd. Chaibasa Cement Works, Chaibasa (B N.R.)

295. Comee, Allan Campbell, Esq.,
General Manager, Messrs Kumardhubi, Engineering Works, Ltd., P.O. Kumardhubi, Dist. Manbhum.

296. Dayal, B., Esq.,
Executive Engineer, Arrah Division, Arrah.

297. Comingo, T.B., Esq.,
43A, Inner Circle, Jamshedpur.

298. Dubey, B.P., Esq.,
Asst. Engineer, Bihar P.W.D., Kanki, Ranchi.

299. Ghose, S.K., Rai Sahib,
Executive Engineer, P.W.D., Singhbhum Division, Chaibasa (Bihar).

300 Ghose, Sushil Kumar, Esq ,
66, Chenab Road,
Jamsheedpur

301. Gupta J N Das, Esq.,
Chief Town Engineer, Tata
Iron and Steel Co ,
Jamshedpur (B N Rly.)

302. Gupta. K , Esq.,
District Engineer, Chaibasa,
(Singhbhum)

303. Gupta, S Esq ,
Svarnasan. Bankipore P.O.,
Patna

304. Gupta, B B , Esq ,
Executive Engineer, (M W.)
Ranchi

305 Gupta, K., Esq.,
Engineer, Jharia Water
Board, P O Dhanbad,
(Manbhum).

306. Hoda, N , Esq.,
Assistant Engineer, P W.D.,
Dehri (Bihar)

307 Jayaswal, U S., Rai Bahadur,
District Engineer,
Muzaffarpur.

308 Jha, B. K , Esq ,
Village Banu Chapra, P.O.
Bettiah, District Champaran
(O N. T Ry.)

309. Joti Prasad, Esq ,
Dist. Engineer, Narsinghpur
(Bihar)

310. Maheshwar Prasad, Esq.,
S D.O., P W.D., Jhalda
(Manbhum)

311. Mahapatra M., Esq.,
S D O., Kishanganj, P.O.
Purnea District, (Bihar).

312. Maitra, C D , Esq.,
Assistant Engineer, P W.D.
Basawan, P O. Kudra,
Dist Shahabad .

313. Mehta, Des Raj , Esq.,
Executive Engineer, Patna.

314. Mehta J. K., Esq.,
Senior Asssistant Engineer,
Town Engineering Depart.
Tata Iron and Steel Co.,
Ltd., Jamshedpur.

315. Misra, Chandi Prasad Rai
Bahadur.
Dist Engineer, Monghyr.

316. Mojumdar, A.B. Esq ,
Assistant Engineer, P.W.D.,
P.O Hinoo, Ranchi

317. Murrell, W L., Esq.,
Additional Chief Engineer,
Military Works, P.O. Hinoo,
Ranchi

318 Nandi, R., Esq ,
District Engineer, Shahabad
(Arrah).

319. Nivas, Hari Krishna, Esq.,
Under Secretary, Bihar
P.W.D , Patna

320. Paul, N , Esq ,
Assistant Engineer, Town
Engineering Dept., Tisko,
Jamshedpur.

321. Prasad, A.P , Esq.,
Assistant Engineer, P. O.
Purulia (Bihar).

322. Prasad, Ras Dhari. Esq.,
A.R P. Engineer, Dhanbad.

323. Prashad, B., Esq.
District Engineer,
Hazaribagh.

324. Ram, G S , Rai Bahadur,
District Engineer, Patna,
(Bihar).

325. Rangaswamy, M A., Rai
Bahadur.
District Engineer,
Darbhanga (Bihar).

326. Roy, S K., Esq ,
Retired Chief Engineer and
Secretary to the Govern-
ment of Orissa, P.O. Baunsi,
District Bhagalpur

327. Sarju Prasad. Esq ,
Lecturer, Bihar Engineering
College, Patna.

328. Sharma, Purnanand Esq.,
District Engineer, Santhal
Parganas P.O. Dumka,
(Bihar).

329. Sinha, B., Esq.,
Assistant Engineer, P.W.D.,
No. 1 Sub-Divn., Central
Division, Patna.

330. Sinha, M.P., Esq.,
Assistant Engineer,
Dhanbad Division,
Dhanbad (Bihar).

331. Sohan Lal, Esq.,
Executive Engineer, P.W.D.
New Dak Bungalow Road,
Patna.

332. Sundaram, S. Esq.,
56, Straight Mile Road,
Jamshedpur.

333. Vakil N.H., R.S.,
District Engineer,
Motihari, Champaran.

ASSAM.

334. Ali Ahmed, Esq.,
Chief Engineer, Assam
P.W D., Shillong.

335. Barua, H.P., Esq.,
Executive Engineer, P.W.D.,
Dalawjan T.E.,
Oating (Assam).

336. Chowdhury, S.P., Esq.,
Assistant Engineer,
Kukitadalone, Dimapur,
Assam.

337. Chowdhury, Abid Raza, Esq.,
Asst. Enginer, P. W. D.,
Sylhet Special Works Sub-
Division, Sylhet.

338. Chowdhury, Imamuz-Zaman,
Esq.,
S.D.O., P.W.D., Daboka,
District Nowgong (Assam).

339. Cormack, F.E., Esq.,
Supdg. Engineer, Northern
Circle, Assam P.W.D.,
Shillong.

340 Das, S , Esq.
Asst., Engineer., P. W .D.,
Nowgong (Assam).

341. Devi Dayal., Esq.,
Supdg. Engineer, P.W.D.,
Shillong.

342. De, B.C., Esq.,
Retd., Asst. Engineer,
P.W.D., Sylhet (Assam).

343. Datta, S.K., Esq.,
S D.O., P.W.D., South Shillong Sub-Division,
Pynursla, Assam.

344. Datta, D.C., Esq.,
Executive Engineer,
Nowgong (Assam).

345. Gupta, J.N., Rai Bahadur,
Ex. Engr., Golaghat Divn.
Jorhat (Assam).

346. Gupta Sen, L.C., Esq.,
Asst. Engineer,
Digaru Assam.

347. McLeod, I.M, Esq.,
Garrison Engineer, Dibrugarh Divn., Dibrugarh
(Upper Assam).

348. Nath, Raj Mohan. Esq.
Executive Engineer,
Golaghat (Assam).

349. Romesh Chandra., Esq.,
Executive Engineer, Tezpur
(Assam).

350. Whitby, A.B., Esq.,
Executive Engineer, P.W.D.,
Nowgong (Assam).

351. Varma, R.L., Esq.,
Executive Engineer, P.W.D.,
Shillong.

N.W.F.P.

353 Abdul Rahman, Khan Bahadur,
Supdg. Engineer, Northern
Circle, P.W.D., Peshawar.

354 Brown, G A.M. Esq.
Chief Engineer, P.W.D., Peshawar.

355 Hardit Singh, Esq.
Executive Engineer, P.W.D.,
Malakand Divn., Malakand
(N.W.F P.).

356 Khan, Mohd Said, Esq.
Executive Engineer, P.W.D.,
Peshawar, Buildings Division,
Peshawar (N.W.F.P.).

357 Khan, Fazal Haq, K S.
Executive Engineer, P.W.D.,
D.I Khan N.W.F.P.

358 Kaushal, R.L. Esq.
Jagannath, Dist. Mardan
(N.W F P).

359 Khatri, K C. Esq.
Executive Engineer, P.W.D.,
D.I. Khan. N.W.F.P.

360 Lawley, W. Esq.
Superintending Engineer,
Bannu, P.W D , Bannu,
N.W.F P.

361 Malhotra, B.R., Rai Saheb,
Executive Engineer, P.W.D.,
D.I Khan. N W F.P.

362 Naqvi, M.H., E q.
Executive Engineer, P.W.D.,
Peshawar.

363 Oram, A., Lt. Col.
Chief Engineer, (Retired),
P.W D., Peshawar.

ORISSA

364 Basu, H.L. Esq.
Dist. Board Engineer,
Chatrapur, Ganjam.

365 Bhuyan, M N. Esq.
Executive Engineer, P.W.D.,
Northern Divn., Cuttack.

366 Bose, K.M Esq.
District Engineer, Sambalpur.

367 Das, P.C. Esq.
S.D O., P.W.D , Jabra
Workshop, Cuttack.

368 Fleury, W.R. Esq
Under Secretary, P.W.D.,
Cuttack

369 Green, A E , Captain,
Chief Engineer and Secretary
to Govt., Orissa P W.D.,
Cuttack.

370 Iyer, E.V.S Esq
Executive Engineer, P.W.D.,
Koraput, Orissa

371 Jootla, Baboo Singh, Esq.
Sub-Engineer, P.W.D.,
[illegible]

372 Padi, Sita Ram, Esq.
Asst Engineer, P W D., Nowrangpur, Koraput, (Orissa)

373 Palit, S K. Esq.
Asst. Engineer, Akhuapada
Sub-Division, Akhuapada,
District Balasore.

374 Parija, K C Esq.
Assistant Engineer, P O.
Nawapara, District Sambalpur

375 Pujari, Achyutnanad, Esq.
Executive Engineer,
Southern Divn , Cuttack

376 Rao, V V. Esq.
District Board Engineer,
Berhampore, Ganjam District.

377 Ray, G P. Esq.
District Board Engineer,
Puri (Orissa).

378 Sarma, P V.N. Esq.
Asst. Engineer, Jeypore,
Samasthanam, Jeypore,
Koraput, Dist. Orissa.

379 Senapati, G N. Esq.
Asst Engineer, P.W.D.,
Berhampore (Ganjam).

380 Sinha, A.K. Esq.
Dist. Board Engineer,
Chandno Ghowk, Cuttack

381 Sahu, B.N. Esq.
Asst. Engineer, P.W.D.
Phulbani, Orissa.

SIND

382 Ajwani, H J. Esq.
Assistant Engineer,
Khairpur Mirs (Sind)

383 Bhatia, K.M. Esq.
Executive Engineer, Fubli
Division, Hyderabad (Sind).

384 Bhagat, D G Esq.
Executive Engineer,
Hyderabad (Sind).

385 Bhojwani, N G Esq.
Executive Engineer, P.W.D.,
Larkana (Sind).

386 Bushby, W.E. Esr.
Chairman, Karachi Port
Trust, Karachi.

387 Daryanani, C.S. Esq.
C/o P.Box No. 115, Karachi.

388 Dhamani, Pessumal Narumal, Esq.
Asst. Engineer, and P.A. to
the State Engineer,
Khairpur Mirs' (Sind)

389 Divatia, S S Esq.
Executive Engineer, P.W.D.,
Hyderabad (Sind).

390 Griffiths, W. A. Esq.
Burmah-Shell Oil Co., Ltd.,
Karachi.

391 Jivarajani, P.R. Esq.
Deputy Soil Classification
Officer,
Karachi (Saddar).

392 Malik, Jaswant Singh. Esq.
Superintending Engineer,
(Roads) Sind,
Karachi (Saddar).

393 Madhav, T K. Esq.
Sub-Engineer, Municipal
Corporation, Karachi.

394 Ramchandani, N.R. Esq.
Executive Engineer, P.W.D.,
Construction Division,
Hyderabad (Sind).

395 Ramchandani, J.R. Esq.
Assistant Engineer, P.W.D.,
D.B. Barrage Township,
Sukkur (Sind).

396 Rijwani, J.M. Esq.,
Superintending Engineer,
(Roads), Karachi (Sind).

397 Shahani, C.M. Esq.
C/o B R. Herman and
Mohalla Ltd., Wood Street,
P.O. Box No. 11, Karachi.

398 Shivdasani, K.J Esq.
Chief Officer and Engineer,
District Local Board,
Larkana (Sind).

399 Shaikh, M A M. Ebrahim Esq.
Assistant Engineer, Roads
Sub-Division, No. 3,
Sukkur (Sind)

400 Vaswani, G.B Esq.
Assistant Engineer, Roads,
Municipal Corporation,
Karachi.

M.E S.

401 Bansor, H.S. Esq.
S D.O., M.E.S., Happy
Valley, Shillong (Assam).

402 Basu, N., Lt.
152, Indo Railway, Maint
Coy., C/o 6, Adv. Base P.O.

403. Chadda, Ulfat Rai,
Engineer-in-Chief's Branch,
Army Headquarters,
Fontain Bleau, Simla.

404 Devdhar, V.S Esq.
Surveyor of Works, M.E.S.,
Office of C.R.E. (South),
Camptie.

405 Fenton, B. W., Lt.
344, W/Shop Park Coy.,
I.E, 18A, A.B P.O.
India Command.

406 Lang-Anderson, W.G. Col.
H.Q.G., R.E.F, No. 6,
A.B.P O (India).

407 Nehra, Vidya Sagar, Capt.
A C.R.E (Works), 1/14,
C R.E., Works. Indian,
Imphal (Assam).

408 Shareef, Safdar Ali.
Asst. Garrison Engineer,
M.E.S, Bareilly.

409 Stuart-Lewis, A.
C/o Chief Engineer, Eastern
Army Headquarters.
Calcutta.

410 Venkata Krishniah, D.
Surveyor of Works, Office
of the C.R E., Deolali.

CENTRAL INDIA STATE AGENCY.

411 Adshetti, G K. Esq.
Cantonment Engineer,
Mhow (C I.)

412 Beg, Mirza Fahim, Esq.
Amirganj, Shahjahanabad
(Bhopal).

413 Bhalla, Prem Nath, Esq.,
District Engineer,
Headquarters Works,
Palasia, Indore.

414 Dhodi, S D., Esq.,
State Engineer, Jhabua
State, Jhabua.

415 Doshi, A G., Esq.,
Irrigation Engineer,
Morvi State, Morvi.

416 Gandhi, M M, Esq,
State Engineer, Morvi
State, Morvi (Kathiawar).

417 Gue, T C, Esq,
Chief Engineer,
Rewa State, Rewa.

418 Katar Mal, C. L., Esq.,
State Engineer,
Orchha State, Tikamgarh
(C I.)

419 Khot, N A, Esq.,
Chief Engineer,
Holkar State, Indore.

420 Mohsin Ali, Esq.,
Director of Postwar
Reconstruction, Govt. of
Bhopal, Bhopal.

421 Pancholy, D B, Esq.,
State Engineer, Dharangadhra
State, Dharangadhra
(Kathiawar).

422 Phadke, P.G, Esq.,
Offg. District Engineer,
P.W D, Mandleshwar
(Holkar State).

423 Rao, B M, Esq.,
State Engineer, Dhar State,
Dhar.

424 Rathod, M.P, Esq.,
State Engineer, Palitana
State, Palitana (Kathiawar).

425 Saksena, C.P., Esq.,
S D.O, P.W.D., Rewa
State, Sahdol (B N.R.).

426 Shah, J. Mansukhlal, Esq,
State Engineer, Balasinor
State, Balasinor (Kathiawar).

427 Subba Rao, N, Esq.,
Retd. Chief Engineer,
Holkar State, Indore.

Rajputana State Agency

428 Bammi, D R., Esq,
Asst Engineer, Irrigation
Division, Jodhpur P.W.D.,
Pali Marwar.

429 Bhattacharya, N.G., Esq.,
Executive Engineer, B. & R.,
Jaipur.

430 Bhargava, K.N., Esq.,
Asst Engineer, Roads,
Alwar

431 Bhatnagar, Jagmohan Lal, Esq.,
State Engineer, Brijnagar,
Jhalawar State (Rajputana)

432 Chowdhury, Ram Narain Esq..
'Ratanda', Jodhpur.

433 Edibam, N.R., Esq.,
Chisti Villa, Srinagar Road,
Ajmer.

434 Edgar, S G., Esq.,
Supdg Engineer, P. W.
Minister, Govt. of Jodhpur,
Jodhpur.

435 Furgusson, F.F., Esq,
Director, Public Works,
Jodhpur.

436 Garudachar, B R, Esq,
Chief Engineer, Bharatpur.

437 Hoey George, Mc. Chuseland.
Esq.
State Engineer, Jaipur State
Jaipur.

438 Malik, S.B. Sir Teja Singh,
Chief Engineer, Jaipur State,
Jaipur

439 Mathur, Kishore Lal, Esq,
Assistant Executive Engineer,
P.W.D, Jodhpur.

440 Mckenzie, R.H T., Esq.,
Chief Engineer,
Bikaner State, Bikaner.

441 Pandya, T C, Esq.,
State Engineer, Tonk State,
Tonk.

442 Saigal, Sant Ram, Rai Saheb,
State Engineer, Mewar State,
Udaipur.

443 Sarabhoja, N., Esq.
(Retd.) Chief Engineer,
P.W.D., Brijnagar,
(Rajputana).

444 Sheshagiri Rao, G. Esq.
Chief Engineer., Irrigation,
Jaipur State, Jaipur.

445 Varma, A.P.. Rai Bahadur,
Chief Engineer, (Irrigation),
Bikaner State, P.O.
Sriganganagar.

Western Indian States Agency

446 Bhatt, Upendra J. Esq.
State Engineer, P.W.D.,
Bhavnagar.

447 Dighe V.A. Esq.
Chief Engineer, Janjira State,
Janjira (Murud).

448 Jaswala, J.R, Esq.
State Engineer, Cambay.

449 Jivrajani, M.R. Esq.
State Engineer, Porbander.

450 Mehta, Jagmohandas T. Esq.
'Niketam', Taleja Road,
Bhavnagar.

BARODA STATE & GUJRAT STATES AGENCY.

451 Jadhav, M.K Esq.
State Architect and Acting
Chief Engineer, Baroda State,
Baroda.

452 Modi, A.K. Esq.
The Navsari Electric Supply
Co., Ltd., Navsari.

453 Patil, G K. Esq.
Supdg. Engineer, P.W.D.,
Baroda.

454 Patil, M R. Esq.
Retd. Chief Engineer,
4, Aekapuri, Baroda.

EASTERN STATES AGENCY

455 Behera, S S. Esq.
State Engineer, Gangpur
State, P.O. Sundargarh,
via Jharsuguda (B.N. Ry.)

456 Biswas, N. Esq.
Asst. Engineer, Defence,
P.O. Baripada.

457 De, K.C. Esq.
Irrigation Engineer, P.O.
Sundargarh, Via Jharsugarh
(B.N.R.).

458 Kikkeri, S.A. Esq.
Chief Engineer, P.W.D.,
Mayurbhanj State, Baripada.

459 Plumley, D. J. Esq.
Pub. Works Advisor,
Eastern States Agency,
Raipur.

460 Rath Nilkanth, Esq.
P.O. Karajia, via Tatanagar,
Mayurbhanj State.

461 Ram Chandra Rao, S. Esq.
State Engineer, Nandgaon
State, Rajnandgaon.

462 Ray, J. C. Esq.
State Engineer, P.W.D.,
Cooch Behar.

463 Sen, A K. Esq.
Road Engineer, Tripura
State, P.O. Agartala,
(Eastern States Agency).

MADRAS STATES AGENCY

464 Chakko, I.C. Esq.
Chief Engineer, Travancore
State, Trivandurm.

465 Mathew, P.G. Esq.
Civil Engineer, Kylore House
Olair, Quilon Post,
Travancore.

466 Menon, V.K.A. Esq.
Chief Engineer, Cochin Govt.,
Trichur.

KOLHAPUR STATES & DECCAN STATE AGENCY.

467. Bapat, R. S. Esq.
State Engineer, Phaltan
State, Dist. Satara.
(Deccan States Agency).

468. Bedekar, V. P. Esq.
State Engineer,
Miraj (Senior).

469. Bhave, V. J , Rai Sahib
State Engineer, Sangli.

470. Haval, Anant Balwant, Esq.
Ileaka Panchayat Engineer, Shukrawarpeth, Kolhapur.

471 Kanhere, V P. Esq.
State Engineer, Bhor State, Bhor.

472 Puranik, R G Esq.
State Engineer, Jamkhandi.

473. Ramaswamy, H. Esq.
Asst. Engineer, Bombay, P. W. D , Kolhapur Residency, Kolhapur.

474. Shinde, P. K., Esq.
Chief Engineer, Radhanagari, Hydroelectric Scheme, Kolhapur.

PUNJAB STATES AGENCY AND KASHMIR STATE

475. Colabawala, J. R. Khan Bahadur,
State Engineer, Khairpur Mirs' (Sind).

476. Garr, B L. Esq.
State Engineer, P. W. D., Sirmur State, P.O. Nahan.

477. Gupta, D. N. Esq
Asst. Engineer, Chittar Palaces Sub-Division, Tawi.

478. Khan, G. H. Esq.
Divisional Engineer, Bandipur (Kashmir).

479. Lekh Raj, Esq.
Retd. Civil Engineer, Kapurthala.

480. Mengi, B. N. Esq.
Asst Engineer, Military Sub-Division, Jammu (Kashmir)

481. Nanda, B. D. Esq.
Divisional Engineer, Srinagar, Kashmir

482. Nanda, K. L. Esq.
Divisional Engineer, Palaces Division, Srinagar, Kashmir.

483. Puri Siri Ram, Esq.
State Engineer, Nabha State, Nabha.

484. Qureshi, Mohd. Ayub, Esq.
Resident Engineer, Gilgit.

485. Ram Rakha Mal, Esq
Divisional Engineer, Palaces Divn , Srinagar (Kashmir).

486. Ram Swarup Sardar,
State Engineer, Jind State, Sangrur.

Hyderabad State (Deccan)

487 Abdul Hai Esq.
Assistant Engineer, P.W D., Masaudpore, Nizamabad (Deccan)

488 Amingad, A K Esq.
S D O., P W D., Lingsugar, Dist. Raichur, G I.P.

489 Arifuddin, Syed, Esq.
Retd. Chief Engineer, Hyderabad-Deccan.

490 Asgar, S.A. Esq.
Asst Engineer, P.W.D., C/o Executive Engineer, Saifabad, Hyderabad-Dn

491 Balaprasad, S Esq.
Divl. Engineer, C/o R.L. Soni, & Co , Putti Badli, Hyderabad-Deccan.

492 Chaphalkar, V P. Esq.
Venkatesh Ban, Kachiguda, Hyderabad-Deccan.

493 Dalal, C L Esq.
C/o The Imperial Bank of India, Ltd., Hyderabad-Deccan.

494 Dangoria, C C. Esq.
Divisional Engineer, City Improvement Board, Hyderabad-Deccan.

495 Dildar Hosain, Esq.
Supdg Engineer, Secunderabad (Deccan).

496 Faridon, S. Chinoy, Esq.
Executive Engineer, P.W.D.,
Jehangir Bagh, No. 12,
Chilkalguda, Secunderabad

497 Gopalan, M. Esq.
Special Superintending
Engineer, Capital Works
Circle, Kachiguda,
Hyderabad-Deccan.

498 Hardikar, J.C. Esq.
Executive Engineer, A R.P.,
House No. 414, Hardikar
Bagh, Himayat Nagar,
Hyderabad-Deccan.

499 Iyengar, M.A.R. Esq.
S.D.O., P.W.D., Yadgir,
(G.I.P.Rly), Nizam's
Dominions.

500 Iyer, S.K. Esq.
State Mechanical Engineer,
P.W.D., Workshops,
Hyderabad-Deccan.

501 Iyengar, S.V.G. Esq.
C/o P.W.D., Jagtial,
Karimnagar Dist (N.S.Ry.).

502 Iyengar, C L. Esq.
S.D.O., P.W D, Hazurabad
Via Kazipet, (N.S.Ry.)

503 Kadeer, M.A. Esq.
Divl. Engineer, P W D.,
Khairatabad (Hyderabad-Deccan).

04 Katrak, M M. Esq.
153 'C., Sappers' Lines,
Secunderabad,

5 Khaja, Azeemud-Din, Esq.
Divisional Engineer,
Gundapali Post,
Mahboobnagar.

5 Khan, Md. A. Khuyyum Esq.
Executive Engineer,
P. O. Lalaguda, (Dn).

Khan, Md A Mirza, Esq.
Asst. Engineer P W.D.,
Raichur (Deccan).

508 Khan, A. Samad, Esq.
Asst. Engineer, P.W.D,
Gulbarga, Hyderabad-Dn.

509 Khan, M. A. Subhan, Esq.
Asst. Engineer, P.W.D.,
Nangabad, Hyderabad-Dn.

510 Khan, K. M. Nemat, Esq.
Executive Engineer, P.W.D.,
Medak Division,
P O. Sangareddi,
(Hyderabad-Deccan).

511 Khan, A.R. Esq.
Asst. Engineer, P.W.D.,
Special Division,
Khairatabad,
Hyderabad-Deccan.

512 Khan, Ahmed Ali, Esq.
Superintending Engineer,
Medak Circle, Medak.

513 Khan, Mir Iqbal Ali, Esq.
Executive Engineer, P.W.D.,
Osmanabad.

514 Kosnam, S. S. Esq.
Asst. Engineer, P.W.D.,
Khairatabad,
Hyderabad-Deccan

515 Lakdawala, M. Rustam, Esq.
Asst. Engineer, P. W. D.,
Lalaguda P. O.,
Hyderabad-Deccan.

516 Lokendra Bahadur, Esq.
Executive Engineer, P.W.D.,
15, Saifabad,
Hyderabad-Deccan.

517 Masad-ul-Ullah, M. Esq.
Executive Engineer, P.W.D.,
Bidar.

518 Mirza, Mohd. Ahmed, Esq.
'Saifeena', Saifabad,
Hyderabad-Deccan.

519 Moorthi, T.S. Esq.
Asst. Engineer, P.W.D.,
Khammameth (N.S. Rly.).

520 Mohammed Ashraf, Esq.
Dist. Engineer, Osmanabad,
(Hyderabad-Deccan).

521 Mohd. Farhat-Ullah, Esq.
Executive Engineer,
R.A F Works, Saifabad.

522 Mohd. Vasay, Khaja, Esq.
P.A to Supdg Engineer,
P W D, Medak Circle,
Kachiguda,
Hyderabad-Deccan.

523 Mohd. Ibrahim, Esq.
Asst. Engineer, Anantagiri,
Vikarabad (Dn).

524 Mohd Ibrahim, Esq.
Executive Engineer, P.W.D.,
Gulbarga.

525 Mohd. Asadullah, Esq.
Secretary, War Supply
Advisory Board, Railway
Board Office, Secunderabad.

526. Mehdi Ali, Mirza, Esq.
Asst. Engineer,
Nizamabad
Hyderabad-Deccan

527 Mohd. Athur, Esq.
Asst. Engineer,
P O. Lalaguda, Deccan.

528 Mohd Vajahat Ali, Esq.
Asst Engineer, P W.D,
Bhongir District, Nalgonda
(N.S.Ry.).

529 Mohd. Usman, Esq.
Asst Engineer, P.W.D.,
Hanam Kunda,
Hyderabad-Deccan.

530 Narasimham, J S. Esq
3393, Kingsway,
Secunderabad (Deccan).

531 Najabat Ali, Esq.
Asst Engineer, Nalgonda
Sub-Division, Nalgonda,
N. S Ry.

532 Nawab Ahsan Yar Jung
Bahadur, Esq.
Afsar Manzil, Jubilee Hill,
Hyderabad-Deccan.

533 Ramaswamy, K. Esq.
Asst Engineer, P.W.D.,
Secunderabad-Deccan.

534 Rajan A Deva, Esq.
Municipal Engineer, Raichur.

535 Reddy, B R. Esq.
Asst. Engineer,
Canal Sub-Division,
Hyderabad-Deccan.

536 Saberi Yusaf, M L Esq.
52, George Town,
Secunderabad-(Deccan).

537 Samiullah Shah, Esq.
Superintending Engineer,
Hyderabad- Deccan.

538 Shiva Raj, A Esq.
Dist. Engineer, P.W.D.,
Aurangabad (Deccan).

539 Sitaram Rao, M S. Esq.
Executive Engineer, P.W.D.,
Warangal, Kazipet (N.S.Ry.)

540 Siva Rao, S N. Esq
Chief Engineer's Office.
Hyderabad-Dn.

541 Sriniwasa Iyer K. V. Esq.
Asst. Engineer,
Mahaboobnagar Hyderabad.

542 Surati, H M. Esq.
Assistant Engineer, Valabh
Das Estate, Public Garden
Road, Hyderabad-Deccan.

543 Syed Ali Raza, Esq.
Executive Engineer,
P W D., Raichur
(G.I P. Ry.).

544 Tata, K. Rao, Esq.
Sectional Officer,
Basmothnagar, Parbbani
District, Deccan (N.S R.).

545. Turab, Mohd. Abu, Esq.
Supdg Engineer, Baitu-Fazal, Moazzamzali Road, Hyderabad-Deccan.

546. Venkatachellam, K. Esq.
Sub-Engineer, P.W D., Jaceeol, Karimnagar Dist., (N.S Ry.), Via Paddapathi.

547. Younus, S.M. Esq.
Inspecting Engineer, Aerodromes Project, Saifabad, Hyderabad-Deccan.

MYSORE STATE

548. Bennet C M. Esq.
Ulsoor Road, Bangalore.

549. Gangadhara, K S. Esq.
Assistant Engineer, Aviation Division, Kolar (Mysore State).

550. Lakshminarasimhaiya, N. Esq.
Supdg Engineer, Jog Falls, P.O., Shimoga Dist. (Mysore State).

551. Narasimha Ayyar, M.K. Esq.
Executive Engineer, Hirabhasgar Division, P. O. Sagar, Shimoga.

552. Narasimha Ayyangar, N. Esq.
Executive Engineer, Kolar.

553. Rajam, M.K. Esq.
Supdg. Engineer. Shimoga Circle, Shimoga.

554. Rama Rao T. Esq.
Executive Engineer, Mysore Division, Mysore.

555. Sirsi, B.R. Esq.
S.D.O., Jalahalli (Mysore State).

556. Srinivasa Moorthi, K.V. Esq.
Assistant Engineer, Ghavnapatna (Mysore).

557. Windkler, L.A.H. Esq.
Chief Engineer, Mysore, Bangalore.

GWALIOR, RAMPUR AND BENARES STATES

558. Athawle, Esq.
District Engineer, Ujjain.

559. Bhonsale, N. K., Major,
Chief Engineer, Lashkar, Gwalior.

560. Chowdhury, P. M. Esq.
District Engineer, P. W. D., Ujjain (Gwalior).

561. Datta, S. N. Esq.
Supdt., Water Works, Gwalior.

562. Dhumal, R. J. Esq.
Inspecting Engineer, P. W. D., Gwalior.

563. Divatia, P. V. Esq.
Executive Engineer, Special Works, Gwalior.

564. Dixit, M. K Esq.
C/o Lashkar Municipal Committee, Lashkar, Gwalior.

565. Ghatge, Krishna Rao Raghoji, Esq.
Genl. Manager, Scindia State Rlys, Gwalior.

566. Gupta, K. K. Esq.
Hind Construction, Gwalior.

567. Gupta, S. C. Esq.
Asst. Engineer, Special Works, Gwalior.

568. Handa, K. L. Esq.
District Engineer, P. W. D., Sardarpur (Gwalior), via Mhow.

569. Inamdar, S R. Esq.
District Engineer, P.W.D., Morena, Gwalior State.

570. Jeyram, Yadav, Haris Chandra, Esq.
Dist. Engineer, P.W D., Gird (Gwalior).

571. Johri, Brij Mohan, Esq.
District Engineer, P.W.D., Blind (Gwalior State).

572. Khan, N.M. Malik, Esq.
Inspecting Engineer,
Lashkar (Gwalior).

573. Khan, Abdul Jabbar, Esq.
Executive Engineer, P.W.D.
Rampur State (U.P.)

574. Mane, Y G. Esq.
District Engineer, P.W.D.
Guna, Gwalior State.

575. Moghe, L V Esq.
District Engineer, P.W. D.,
Mandsaur (Gwalior).

576. Naik, B G. Esq.
Assistant Engineer,
Maharapore (Gwalior).

577. Naidu, Narayan Rao, Esq.
Asst. Engineer, Messrs.
John Tinson & Co., Ltd,
Procession Road, Lashkar,
Gwalior.

578. Patil, B D. Esq.
Dist. Engineer, P W.D.,
Shivpuri, (Gwalior).

579. Patil, Y K. Esq.,
Asst Engineer, P. W. D,
Lashkar (Gwalior).

580. Rish Raj, Esq.,
Asst Secretary,
Indian Roads Congress,
Simla.

581. Sharma, Baij Nath, Esq.
Engineer, P W.D,
Shujahpur (Gwalior).

582. Srivastava, Hari Shankar, Esq.
Military Engineer,
Lashkar (Gwalior).

583. Vaidya, Anant Ganesh, Esq.
Project Engineer, P.W D.,
Gwalior.

ASSOCIATE MEMBERS

584. Anderson, J.P. Esq.
Sales Director, M/s. Dunlop
Rubber C (India), Ltd.,
P O. Box No. 391,
Calcutta.

585. Bakewell, W B, Captain.
C/o Bitumen Emulsions
(India) Ltd, Lahore Cant.

586. Chinoy, Nur Mohammed Esq.
C/o The Bombay Garage,
Chowpatty, Bombay.

587. Davidson, J C.F. Esq.
C/o Bird & Co.
Oriental Buildings, Lahore.

588. Lumba, H S. Esq.
Civil Engineer, and Works
Manager, Messrs. Rohtas
Industries, Ltd.,
Dalmianagar, Dist.
Shahabad (Bihar).

589. Madden, W. J., Major,
921, India Works, Section I.E.,
No. 6 A B P.O. (India).

590. Malani, C T S Esq.
C/o Messrs Standard
Vacuum Oil Co,
Finley House, Karachi.

591. Marschalko, Th. C Esq.
Chief Engineer, Caltex Co.
(India) Ltd., Bombay.

592. Nazareth, C V. Esq.
C/o The Consulting
Engr Rds,
Kennedy House, Simla

593. Ormerod, H E., Esq.
C/o Cecil Hotel, Old Delhi.

594. Stevens, G. Esq.
C/o Anamalai Planters
Association, Sholayar, P.O.
Coimbatore Distt.

595 Hewitt, R C.L. Esq.
C/o The Bank of New South
Wales, Wellington
(New Zealand).

596. Hodgson, S E, Esq.
Overdeans Court, Diffen
Hall, Near Farham, Surrey
(England).

597. Hughes, H. Esq.
C/o S.C.E. Naval Works
Office, Colombo (Ceylon).

598. Meares, C.D.N., Brig.
C/o A.P.S., Nairobi, Kenya
(South Africa).

599. Stainer, T.W.
C/o Avelling Barford, Ltd.
Grantham, (England).

600. Wooltorton, F.L.D. Esq.
C/o Lloyds Bank, 399,
Oxford Street, London
(England).

OTHER MEMBERS.

601. Nicolson J.F.H. Esq.
Chief Engineer, Burma
P.W.D., Yodha Niwas,
Simla.